THE SEAS

OUR KNOWLEDGE OF LIFE IN THE SEA AND HOW IT IS GAINED

BY

F. S. RUSSELL & C. M. YONGE

Given in Loving Memory of

Raymond Braislin Montgomery
Scientist, R/V Atlantis maiden voyage
2 July - 26 August, 1931
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Woods Hole Oceanographic Institution
Physical Oceanographer
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Faculty, New York University
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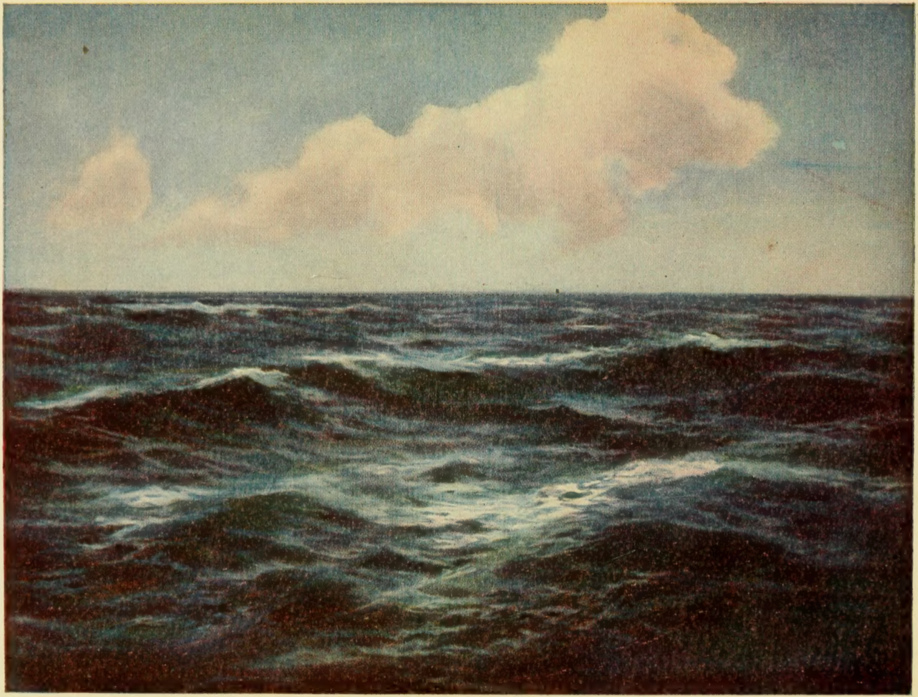
Faculty, Johns Hopkins University
1954-1961
Professor of Oceanography,
Johns Hopkins University
1961-1975

R B Montgomery

1935

THE SEAS



Pl. I.

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The Seas.

(From an oil painting by Harold Webb).

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OUR KNOWLEDGE OF LIFE IN THE SEA AND HOW IT IS GAINED

BY

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AND

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WITH 384 ILLUSTRATIONS
167 OF WHICH ARE IN FULL COLOUR

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To

E. J. ALLEN

PREFACE

ERRATA.

Preface, p. X, line 20. Text figs. 36 & 37, are from "Science of the Sea," and insert Plates 63 and 64, from Charles Darwin's "Coral Reefs."

Page 25, line 5. "Blue Algæ"—should read "Blue-green Algæ."

,, 145. Text fig. 32—the words "male" and "female" should be transposed.

,, 205, line 9. "vulnerable" should read "invulnerable."

,, 208, line 4 from bottom. Delete—"with its huge mouth wide open."

,, 239 line 21, for "Pacific Ocean" read "Southern Ocean."

, 261, plate 95, in legend "x ca 20" should read "x ca $\frac{1}{20}$."

have been written by Mr. Russell, and Chapters I (second half), II, III, VI, VII, VIII, IX, XIV and sections of XVI by Dr. Yonge.

We should like to take this opportunity of expressing our thanks to Dr. E. J. Allen, F.R.S., Director of the Plymouth Laboratory, and to the members of the staff of

the Marine Biological Association for the unfailing interest they have shown in this work, and for the many helpful criticisms and suggestions that they have made; and especially to Mr. H. W. Harvey for his great assistance with Chapter X, concerning which the opinions of a modern hydrographer are invaluable.

We are also especially indebted to the Council of the Marine Biological Association of the United Kingdom for their kindness in allowing the publishers to have photographs specially taken at the Plymouth laboratory, and for putting the laboratory and library at the disposal of Mr. W. J. Stokoe.

We are grateful to our wives for the great assistance they rendered in the preparation of the manuscript, and to the father of one of us, Mr. W. Russell, for his care in reading through the MS.

It has been our aim to illustrate this book with as many original drawings and photographs as we could obtain, supplemented by many beautiful illustrations buried away in the mass of scientific literature and so unfortunately hidden from the eyes of most people. This end could not have been achieved without the cordial co-operation and assistance received from all sides—personal friends, societies, and publishers—and to all and sundry we wish to express our gratitude. We are especially indebted to Mr. Douglas P. Wilson for so lavishly placing at our disposal his many beautiful photographs of shore life from which we chose the illustrations for the following plates: 8, 9, 10, 11, 12, 14, 15, 16 bottom, 18, 20, 22, 45 top, 46 bottom, 87, 109 top, 127 bottom; to Dr. Marie V. Lebour for the original paintings for Plates 40, 43, 44, 88; to Mr. W. Russell for the original paintings for Plates 31, 50; to Dr. T. A. Stephenson for Plate 16 top, and to Mr. H. O. Bull for Plate 29; and to Mr. Harry Vandervell for per-

mission to reproduce the original painting by Mr. Norman Wilkinson, Plate 102. For original photographs our thanks are due to Mr. C. F. Hickling for Plate 99 ; Dr. E. J. Allen, F.R.S., for an endpiece ; Mr. F. M. Davis for Plates 95, 118 left ; Mr. E. Ford for Plate 119 ; Mr. N. J. Berrill for Plate 7 bottom ; Professor R. Dohrn for Plate 5 ; Mr. Hammond for Plate 11 ; Mr. K. Hartley for Plate 96 right ; Institution of Civil Engineers for Plate 57. Permission has been kindly granted by the authors of many original works to reproduce illustrations, amongst whom we wish to thank Mr. C. Tate Regan, F.R.S., for text-figure 17 ; Dr. Henry B. Bigelow for Plates 42 top, 46 top ; Mr. Meade-Waldo for text-figure 22 ; Professor A. C. Haddon F.R.S., for text-figure 16 ; Professor Johs. Schmidt for Plate 35 and text-figure 13 ; Dr. Werner Klinkhardt for Plate 30 ; Dr. B. W. Evermann for Plate 60 ; Dr. W. T. Calman, F.R.S., for Plates 80 top, 89 top ; Dr. J. Travis Jenkins for text-figure 49 ; to Professor S. J. Hickson for text-figure 65 from his " Introduction to the Study of Corals " ; to Dr. E. W. Cudger for plate 32 ; to Mr. J. T. Nichols for Plate 42.

Our thanks are also due to the following societies and scientific institutes for allowing us to reproduce illustrations from their publications and in many cases for the loan of blocks ; the Royal Society, London, for Plate 35 and text-figure 17 ; to the Zoological Society, London, for Plate 123 bottom and text-figure 22 ; to the Natural History Museum, South Kensington, for text-figures 20 and 21 ; to the Marine Biological Association of the United Kingdom for Plates 7 top, 49, 118 right, and text-figures 43, 45 ; to the Norfolk and Norwich Naturalists' Society for text-figure 18 ; to the Director of the Stazione Zoologica, Naples, for Plates 5 top, 27, 39, 41, 56 ; to the Institute of Oceanography, Monaco, for Plate 28 ; to the

American Museum of Natural History for Plates 32 bottom, 42 bottom, 103, 104, 123 top; to the Bureau of Fisheries Washington, for Plates 42 top, 46 top, 67, 69; to the Smithsonian Institution, Washington, for Plate 35; to the Ray Society, London, for Plates 77, 81; to the National Research Council, Washington, for Plate 54; to the Carnegie Institution of Washington for Plates 73 left, 93; to Harvard University, U.S.A., for Plate 89 bottom; to the *Discovery* Committee, London, for Plate 103 top.

To the following publishers and others we wish to express our thanks for their kind permission to reproduce many illustrations: The Controller of H.M. Stationery Office, London, for Plates 4, 7, and text-figures 2, 61, from the Report of the Scientific Results of the Exploring voyage of H.M.S. *Challenger*, and text-figure 56; to the Ministry of Agriculture and Fisheries for Plates 95, 111, 118 left, and text-figure 56; to Messrs. Bartholomew for Plate 3 from *The Times Atlas*; to Mr. John Murray for text-figure 3 from the Challenger Society's handbook, *Science of the Sea;* and text-figures 36, 37, from Charles Darwin's *Coral Reefs:* to Messrs. Arnold & Co. for Plates 5 bottom, 45 bottom, 112 top, from Sir William Herdman's *Founders of Oceanography;* to the Government Printing Office, Washington, for text-figure 13; to Messrs. Benn Bros. for text-figures 27, 28, 29, 30, from *Discovery;* to Messrs. Frederick Warne & Co., Ltd., for text-figure 4 from *Shell Life*, by Edward Step, and Plate 112 bottom from *Fishes of the British Isles*, by J. Travis Jenkins; to Messrs. Macmillan & Co., Ltd., for Plates 21, 25 left, 33, 38, 71 top, 72, 76 top, and text-figures 8, 10, from *The Depths of the Ocean*, by Sir John Murray and Professor Johan Hjort, for Plate 25 right from Sir C. Wyville Thomson's *The Depths of the Sea*, and for Plate 80 and text-figure 19 from the *Cambridge Natural History;* to Herr Gustav

Fischer, Jena, for Plates 34, 36, 71 bottom, 73 left, 74, from the Reports of the *Valdivia* Expedition ; to the Cambridge University Press for Plate 61 from *The Desert and Water Gardens of the Red Sea,* by C. Crossland ; to Messrs. L. Reeve & Co., Ltd., for text-figure 34 from *Corals and Atolls,* by F. Wood-Jones ; to the Clarendon Press, Oxford, for Plates 66, 68, 82, from the *Quarterly Journal of Microscopical Science ;* to Herr B. G. Teubner, Leipzig, for Plate 70 from Professor A. Steuer's *Planktonkunde ;* to Messrs. Methuen & Co., Ltd., for Plates 80, 89, from *The Life of Crustacea,* by W. T. Calman ; to Messrs. Duckworth & Co., Ltd., for Plate 84 bottom from *The Great White South,* by H. G. Ponting ; to Messrs. Putnam's Sons, Ltd., for Plate 94 from *The Arcturus Adventure,* by William Beebe ; to the Chemical Catalog Co., New York, for Plates 103 bottom, 104, 123 top, from *Marine Products of Commerce,* by D. K. Tressler ; to the Director of the Government Press, Cairo, for Plate 126 from the Report of the Egyptian Fisheries, 1922, by G. W. Paget ; to Messrs. J. M. Dent & Sons, Ltd., for Plate 124 from *Reptiles and Batrachians* by Boulenger ; to Messrs. W. R. Deighton & Sons, Ltd., for permission to reproduce the original oil painting by Mr. Harold Webb as Plate 1.

Of the remaining illustrations the photographs for Plates 106, 107, 108 and drawings for text-figures 7, 35, 38, 39, 40, 41, 42, 44, 46, 60, 64, were supplied by Dr. Yonge, and the original paintings, drawings and photographs for Plates 17, 37, 48, 51, 91, 101, 115, 117, 125, and drawings for text-figures 1, 14, 15, 23, 24, 25, 26, 51, 52, 54, and 55, by Mr. Russell.

Finally our greatest indebtedness is due to Mr. W. J. Stokoe for the preparation of the many coloured plates, the half-tone plates and text-figures.

We wish to record our gratitude to him for the great skill

and endless pains he has taken to produce the coloured illustrations from original black and white photographs supplied either by Mr. D. P. Wilson or taken specially in the Plymouth laboratory ; for his care in producing the wash and line drawings under our directions ; and for his generous assistance and advice in all matters pertaining to the arrangement of the illustrations.

F. S. RUSSELL.
C. M. YONGE.

CONTENTS

THE SEAS

CHAPTER I

General Introduction

The Oceans

"Oceanus," son of Heaven and Earth, was the name given by the Greeks in days gone by to an ever-flowing river that they supposed to flow around the earth they thought was flat. Later the name became applied to those waters that were far outside the range of land, being first used to signify the Atlantic Ocean which lay beyond the Pillars of Hercules. To this day the name has the same significance and differentiates the great open water masses from the seas, gulfs, and straits, that lie around their borders. The Atlantic, the Pacific, and the Indian, are the three great oceans of the world. The first, the grave of the mythical Atlantis; the second, named "El Mar Pacifico," by Magellan, so calm were his first weeks therein; the third called after the great country that bounds it on the north. In addition, the waters that surround the North Pole and those that lie along the coasts of the Antarctic continent, are sometimes termed the Arctic and Great Southern oceans respectively.

Around the borders of these oceans lie the enclosed seas cut off by narrow straits, such as the Mediterranean, the Baltic Sea, and the Persian Gulf; the fringing or partially

enclosed seas, separated from the oceans by islands or peninsulas, such as the Behring Sea and the English Channel ; gulfs and bays, such as the Gulf of Aden, Gulf of Maine and Bay of Bengal ; and straits such as the Straits of Gibraltar and of Dover.

Over two-thirds of the earth's surface is covered thus by the oceans and their adjacent waters, the actual proportion of the water to the land masses being according to latest computations about 2.4 to 1. These water masses are not distributed evenly over the surface of the earth, only 43 per cent. lying in the northern hemisphere as opposed to 57 per cent. in the southern. The ratio of water to land also varies in the different hemispheres and it is possible to divide the earth into a water hemisphere whose centre lies a little south-east of New Zealand and a land hemisphere with a centre near the mouth of the Loire in France. Even in the land hemisphere the water area exceeds that of the land by a small amount, while in the water hemisphere only one-tenth is dry land.

Along the coasts of the great continents the water is comparatively shallow and a shelf is formed, either by erosion of the land through the ceaseless battering of the waves against its shores, or by the seaward extension of deposits of mud and silt brought down from the interior of the continents by great rivers, or by the gradual submergence of the land itself. Thus there is a plateau, the Continental Shelf (Fig. 1), from which the dry land emerges above the water level. This area of shallow water, extending down to a depth of about one hundred fathoms, varies considerably in width. It is widest in those regions where there has been a gradual submergence of land, such as in the North Sea into which also are carried mud and silt from the many rivers on the surrounding land. It is narrowest where there has probably been an upheaval of

land and where there is an absence of rivers to extend, in a seaward direction, with their deposits such shallows as have been formed by erosion through wave action. Such regions are on the western coast of North Africa, and the Californian coasts of America. The effect of rivers in widening this shelf can be very clearly seen on the north coast of Egypt where it stretches out for over forty miles in the neighbourhood of the Nile mouths, while 100 miles west of Alexandria the 100 fathom line is reached within five miles.

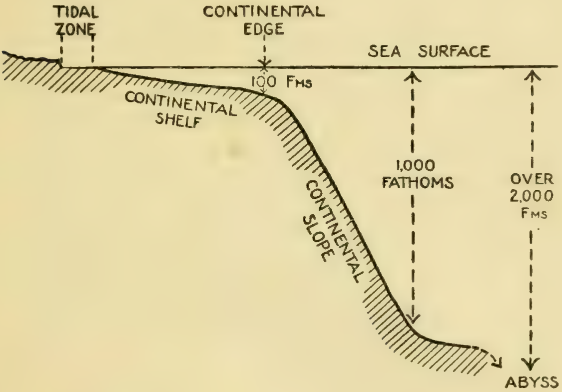


FIG. 1.

From the outer edge of the continental shelf starts the Continental Slope which is generally taken as stretching down to 900 or 1,000 fathoms. This slope is comparatively steep and may be said to constitute the sides of the ocean basins. Its upper limit, the 100 fathom line and outer edge of the continental shelf, is sometimes known as the Continental Edge.

After a depth of 1,000 fathoms is reached the slope of the sea floor becomes almost imperceptible and is probably in most places not unlike a vast and slightly undulating plain. Although it stretches down hundreds of fathoms deeper, its extent is so great that in most places we should be unable to appreciate any gradient whatever.

From about 2,000 fathoms downwards this very gradually shelving ocean bed is known as the Abyss or Abyssal Plain. Although almost level compared with our standards on land, the whole bed of the ocean is not absolutely flat but presents considerable variation in depth over large areas. There is, for instance, stretching north and south through the whole Atlantic ocean a continuous ridge between one thousand and two thousand fathoms in depth surrounded on either side by water down to 4,000 fathoms deep (Plate 3). From this ridge rise the oceanic islands of the Azores. The Saint Paul Rocks, Ascension and Tristan d'Acunha. But it is only in the immediate vicinity of these islands that there is any appreciable slope. Soundings have been taken continuously over great distance by transoceanic cable-laying ships, and their results bear out this point: on one occasion only as much as 250 feet being the extreme range of variation in depth through a distance of 100 miles, in water more than 2,500 fathoms deep. Around the before-mentioned oceanic islands which are volcanic in origin, the slopes may, however, be considerable, being as much as 62° for a short distance off Saint Paul.

The regions in which the bottom lies below a depth of 3,000 fathoms are known as "deeps." The greatest depth yet recorded is 5,350 fathoms off the island of Mindanao in the Philippines, in the Pacific. This enormous depth, over six and a quarter miles, is hard to visualize. The reader can perhaps best realize it if he imagine that the highest mountain in the world, Mount Everest, be sunk

upon this spot, when its loftiest peak would be fully covered and lie over half a mile beneath the ocean surface (Plate 2).

These deeps are not very numerous and cover only a small proportion of the ocean floor. There are 57 in all, 32 of which are in the Pacific, 5 in the Indian Ocean, 19 in the Atlantic, and one lying partly in one and partly in the other of the latter two oceans. Each deep has been given a name, such as the "Murray Deep" and the "Valdivia Deep," after well-known oceanographers and research vessels. The deepest sounding in the Atlantic ocean is 5,227 fathoms, off Porto Rico.

Taken as a whole the depth of the oceans is very great, for more than half of the ocean floor lies between two and three thousand fathoms, while well over three-quarters is deeper than a thousand. One realizes how comparatively trivial in extent is the shallow water that lies around our coasts when it is known that the average depth of the oceans and their adjacent seas is over two and a quarter miles

Ancient Beliefs

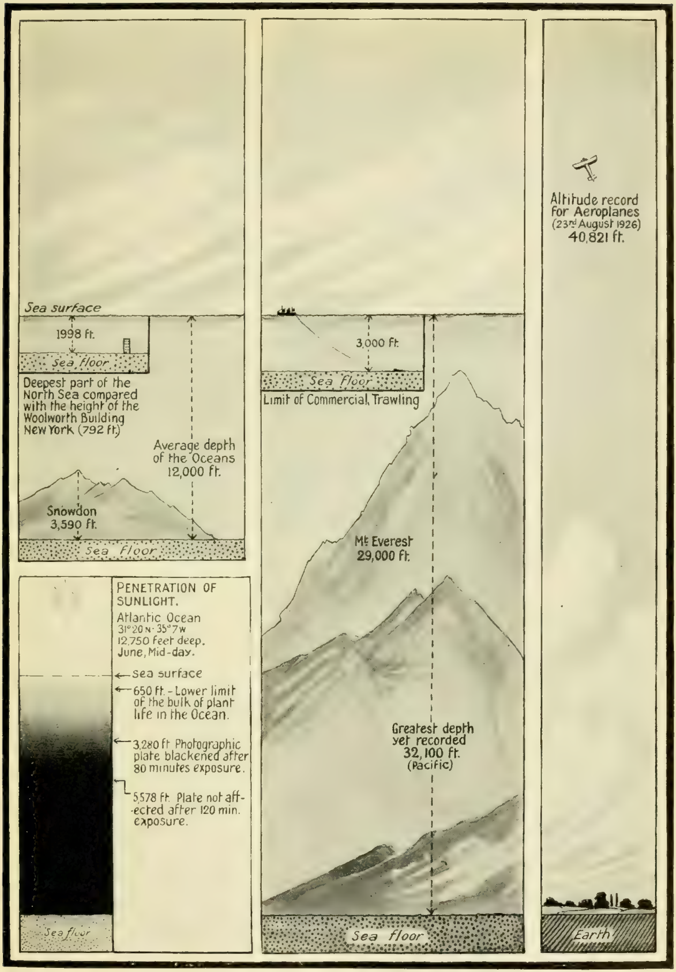
The extent of the oceans was not known to the ancients and their ideas of what lay beyond the small world they knew were probably mostly surmise and myth handed down from generation to generation. The Chaldeans imagined that the earth, which floated upon the eternal waters, was surrounded by a ditch in which a river perpetually flowed. The Egyptians likewise conceived ever-flowing around their world a river on the surface of which floated a boat carrying the Sun. But neither of these civilizations can be said to have been maritime, and it was the Phœnicians who were the great navigators of ancient history. Their knowledge of the extent of the sea must have been very considerable, since they ventured often through the Pillars of Hercules, visiting the coasts of Europe and the British Isles. From

their accounts of floating seaweed it has been thought that they may have been drifted by easterly winds as far west across the Atlantic as the Sargasso Sea.

But few of the Phœnician records have been preserved and we have no maps showing what they imagined the extent of the oceans to be. It seems that the Phœnicians whose business lay on the sea were unwilling to part with their knowledge and kept many of their trade routes secret. Any knowledge handed on from them to the Greeks was small and even that was vague.

In the days of Homer it was thought that the world was flat and that surrounding the Mediterranean was the land of the few countries they knew, but outside the land flowed an ever-running river which they called the ocean (Plate 4). In the sixth century B.C. Pythagoras considered that the earth was a sphere and in the fifth century Herodotus recorded further advances in knowledge. He, however, considered that the south and west of the then known world were bounded by the ocean, but could say nothing of the north and east (Plate 4). By the third century the idea of parallels of longitude and latitude had been introduced by Eratosthenes, and seventy years later Hipparchus instituted a method of map projection. This ancient era in map-making culminated in the description of the world by Ptolemy in A.D. 150, who imagined that the Atlantic ocean and Indian ocean were great enclosed seas, and that if one sailed into the Atlantic from the westernmost point of land the countries of the east would soon be reached (Plate 7).

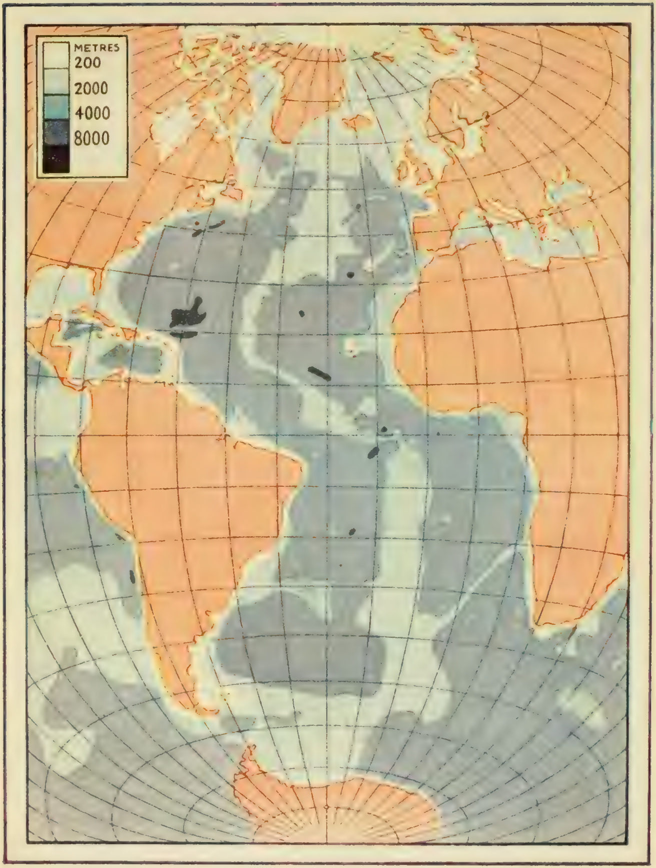
Thus we see that the world of these ancient civilizations consisted of the lands to which they had access on foot and a few countries separated only by short distances of sea, and the two oceans, the Atlantic and Indian, that bathed the shores of the known land. They had no knowledge of the Pacific.



Pl. 2. *B* 6.

Depths of the Ocean (pp. 5, 227).

The limit of commercial trawling shown is the *extreme* limit; the deepest trawling for hake is only economical down to a depth of about 2000 feet. 1 fathom = 6 feet = 1·83 metres.



Pl. 3. *B* 7.

Map showing depths of Atlantic Ocean (p. 4).

1 Fathom = 6 feet = 1·83 metres.

From the fourth century A.D. onwards, when civilization suffered at the hands of barbarian invaders, knowledge of the geography of the world received a great setback. Fantastic suggestions were made as to the shape of the world, and Isidore of Seville in the seventh century originated the "wheel maps" in which the world was represented as being surrounded by a circle of water as was thought in Homeric times (Fig. 2). In addition the world

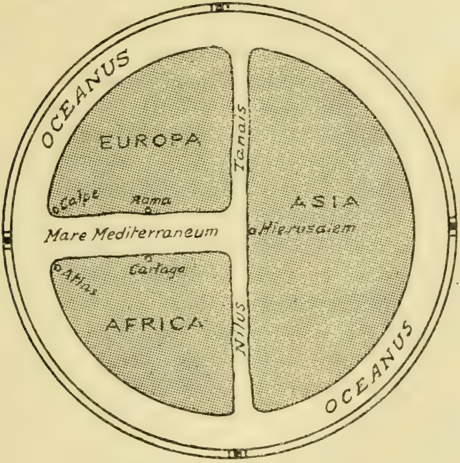


FIG. 2.—Wheel Map of Isidore of Seville.

was cut up into three portions by waters connected with this circle of ocean, an eastern portion, Asia, and two western portions, Europe in the north and Africa in the south. For many years little advance was made save for information obtained by Norsemen in the north and voyages of the Arabs in the east, and in the fifteenth century the maps of Ptolemy reappeared. But the knowledge of the oceans

of the world was soon to receive a great impetus, for from 1420 until his death in 1460, Prince Henry of Portugal, known as the "Navigator," did all he could to encourage maritime research and exploration. During his lifetime much of the coast of western Africa and the eastern parts of the Atlantic were explored and charted, and his enthusiasm may be said to have prepared the way for the great voyages of exploration that were to follow. In 1486 Bartholomew Diaz rounded the Cape of Good Hope and thus opened up the connection between the Atlantic and Indian oceans. On October 12th, 1492, Christopher Columbus set foot on the island known by the natives as Guanahani, after having crossed the Atlantic ocean. This island, which he named San Salvador, is generally thought to be that now known as Watling Island. For many years after this, expeditions sailed to the continent of America, but it was still thought that this continent was joined to the most eastern lands then known, as was considered to be the case in Ptolemy's time. In 1497 Vasco da Gama, rounding the Cape of Good Hope, reached India for the first time by sea. But the final link in the chain of knowledge of the great oceans was forged in September, 1513, when Vasco Nunez de Balbao laid eyes upon the Pacific ocean, a mass of glittering waters that dispelled for ever the idea that India and America were joined by land; and in 1520 Ferdinand Magellan sailed through the straits that bear his name into the "Great South Sea" that he called the Pacific, and although he himself never lived to see the day one of his vessels at last reached Spain in 1522, having circumnavigated the globe.

History of Oceanography

Let us pause to consider the true meaning of oceanography. It is perhaps one of the most composite of sciences,

involving as it does the many branches of knowledge that pertain to a study of the life and conditions of the environment in the oceans and seas. The study of the ocean currents, the tides, the temperatures, and the saltness and other chemical properties, is approached through pure physics and chemistry. The charting of the ocean margins and the mapping of the relief of the ocean beds are matters for physical geographers. Intimately bound up with the great ocean currents and the tides are meteorological and astronomical phenomena. The above studies constitute hydrography, although this term is more usually applied to the survey and charting of those features only which have a direct bearing upon navigation. There remains the study of the life in the sea, marine biology, which involves zoology, botany, bacteriology, and includes the study of animal and plant development, the study of the abundance of life, and many other problems; to these must be added the application to the fishing industry of all knowledge of life and conditions of life in the sea, fishery research. This composite whole makes up the science of oceanography, which can be summed up as the study of the world beneath the surface of the sea.

It is evident, therefore, that up to 1522 when Magellan sailed into the Pacific ocean the true science of oceanography had not begun; all these exploratory voyages had but touched the margin of the geographical side. It is true that Magellan made a sounding in the Pacific ocean, but somewhat naïvely he argued that because he could not touch bottom he had reached the deepest part of the ocean. Soundings are recorded also in ancient times, but as yet there was no systematic attempt to map in relief the ocean bed; in fact it is doubtful whether, owing to the backward state of other sciences, it would then have been possible. It is only within the last few years that it has been made rapid and simple by the introduction of echo sounding.

The progress of oceanography, therefore, must march side by side with the advance of the sciences of which it is built up.

The first true oceanographical expedition sailed when Captain James Cook started on his voyage of discovery in 1768 in the *Endeavour*. On this expedition both temperature observations and deep sea soundings were made, and included in the ship's company were the Astronomer Royal and a noted biologist.

From this time onwards until about 1860 many exploratory voyages were undertaken on which true oceanographical work was carried out, such as the expedition to the Antarctic in 1839 in the *Erebus* and *Terror* under Sir James Ross. At this period also the knowledge of marine zoology and botany grew quickly and new facts were being discovered by naturalists who went out in naval surveying ships. In 1831 Charles Darwin sailed in H.M.S. *Beagle*; in 1846 H.M.S. *Rattlesnake* took with her Thomas Huxley, and in 1860 H.M.S. *Bulldog* went cruising with G. C. Wallich on board. Little was, however, known of the life on the deep ocean beds, and it was generally believed that the conditions found there would completely prohibit the existence of living animals. Occasionally organisms had been brought up attached to deep sea sounding-leads, but there was the possibility that these had become entangled while the rope and lead were hauled through the upper water layers.

More substantial evidence that life really existed at the great depths came when submarine cables were invented, and the salving of broken cables showed growth of marine organisms upon them.

In 1868, H.M.S. *Lightning*, followed later by H.M.S. *Porcupine*, proceeded with naturalists on board to settle the question once and for all by deep sea dredging. We can imagine the suspense of the little group of men on board when the dredge was at last nearing the surface; for deep

sea dredging is a lengthy business, the dredge taking many hours to be lowered and hauled through the enormous depths. They were not disappointed; living animals were present at the greatest depths; and an added excitement arose, every haul brought up strange and beautiful organisms that man had never yet set eyes on.

The time was now deemed ready for a great expedition to explore all the oceans of the world, to study animal and

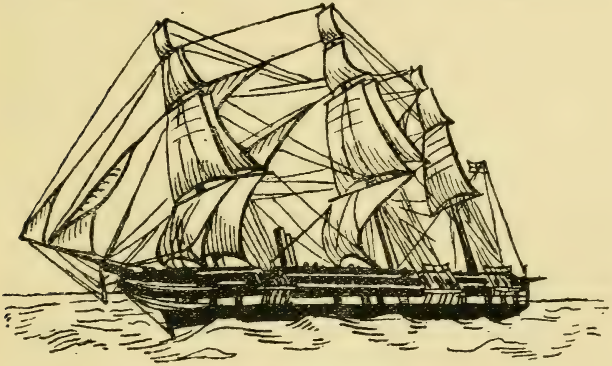


FIG. 3.—H.M.S. *Challenger*.

plant life and the chemical and physical conditions under which they existed. Accordingly in 1872 Her Majesty's Government commissioned the famous research ship, H.M.S. *Challenger*, under command of Captain Nares, carrying on board some of the most noted men of science of the day, headed by Sir Wyville Thomson. This ship (Fig. 3) sailed the oceans for three years, travelling in that time 69,000 miles. Soundings were made the world over, temperatures noted, and samples of water taken from all depths; samples of the sea floor were obtained;

dredgings were made in the great abyss, and nets towed in the water layers between the surface and the bottom.

The information obtained gave work to a large body of specialists and resulted in the famous "Challenger" reports, which may be said to form the solid base upon which the superstructure of the science of oceanography has since been built.

These results placed the science on a sure footing, and later expeditions went out with a good idea of the conditions to be expected, so that plans could be laid for special problems of interest that had to be tackled. Better instruments were invented and, most important of all, wire came into general use replacing the old bulky ropes, Alexander Agassiz being the first to use it on the voyages of the *Blake*, from 1877 to 1880.

Expeditions sailed from many countries, and since the time of the *Challenger* some of the more important were the Deep Sea expedition of the Germans in the *Valdivia*, and the voyages of the *National* and *Deutschland* from the same country; the cruises of the Norwegian vessel, the *Michael Sars*, under Professor Hjort, and Sir John Murray of *Challenger* fame; the famous voyages of Captain Scott and of Sir Ernest Shackleton, and many others.

Recently two very important cruises have been completed. That of the *Discovery*, Captain Scott's old ship, which has been carrying out oceanographical work in the South Atlantic and studying the life-history of the whale under the auspices of the Falkland Islands Dependencies; and that of the German cruiser, the *Meteor*, which has been engaged in making a complete survey of the ocean bed of the South Atlantic by means of echo-sounding, and taking many hundred water samples to study the current system of the ocean.

In the year 1901 was formed what is known as the

"International Council for the Exploration of the Sea." This council is now composed of delegates from Norway, Sweden, Denmark, Finland, Germany, Great Britain and Ireland, France, Belgium and Holland. It has as its prime object the improvement of the Fisheries of the North Sea and surrounding waters, for these great fishing areas are international in character. These countries undertake to fit out permanent research vessels and to study definite problems in the various areas of the sea allotted to them.

Marine Laboratories

The foundations of the science of oceanography were laid, as we have seen, by the work of the great marine expeditions. But the work that such expeditions can do is necessarily limited, they are indispensable for studies of the fauna and flora of the open sea, of the nature and inhabitants of the bed of the oceans, and of the ocean currents and the nature of the sea in different regions; but they are not suited, clearly enough, for examinations of the structure and experiments into the functioning of the animals and plants, or for long continued investigations into the seasonal variations in the constitution of the sea water and its microscopical population, work which, as we shall see later, is of the very greatest importance. For these investigations it is essential that we should have laboratories on the sea coast where marine animals and plants can easily be obtained, where they can be kept in aquaria with running or circulating sea water as near natural conditions as possible, and where regular samples of sea water can be obtained throughout the year and the variations in its chemical and physical constitution and its contained life accurately determined by expert chemists and biologists.

The need for such laboratories has resulted in the founda-

tion of a series of marine stations in the majority of the civilized countries, the work of which has been of the highest importance and promises, in the future, to be even more important. Expeditions are still necessary, we have still a very great deal to learn about the great oceans, but in the future they will extend and supplement the work of the shore stations rather than, as in the past, be an end in themselves.

Among the first and certainly the most famous of these marine stations was founded at Naples in 1872 by a remarkable German zoologist named Anton Dohrn. From the Italian government he obtained a grant of land situated in the Villa Nazionale, a beautiful park lying between the town and the sea, where, with money from the German government and from scientific societies in different parts of the world, but very largely from his own private fortune, he built the famous Stazione Zoologica (Plate 5). Since twice extended, this now consists of three handsome flat-roofed buildings of white stone surrounded by evergreen oaks, palms, cacti and other samples of the beautiful Mediterranean flora and commanding from its upper windows a fine view of the wonderful panorama of the Bay of Naples. All tourists to Naples will know it, for on the ground floor is situated the far-famed Aquarium, one of the recognized " sights " of the city where as nowhere else the visitor can see something of the wonderful Mediterranean fauna of the Bay of Naples. The water which circulates through the aquarium tanks, and also the research laboratories on the upper floors, is pumped up from the Bay, and allowed to stand in huge storage tanks until the sediment has settled to the bottom when the clear water above is drawn off.

Scientists of all nationalities work here, " tables," of which England has three, being rented by the year by scientific institutions in different countries who have the

The World according to Homer, B.C. 1000. (p. 6).

The World according to Herodotus, B.C. 450. (p. 6).

Marine Biological Laboratory, Naples. (p. 14).

Pl. 5. *B* 15.

Marine Biological Laboratory, Monaco. (p. 15).

right to nominate workers, and there are few of the great zoologists of Europe or America who have not worked at Naples during the past fifty years. During the War the station was taken over by the Italian Government, but since then it has been restored to the present Director, Professor R. Dohrn, the son of the founder who died in 1909, but it still remains partly under Italian management.

Even more commanding in its position and architecture is the wonderful museum, laboratory and aquarium founded at Monaco (Plate 5) by the late Prince Albert, one of the most distinguished of oceanographers. Everyone interested in zoology or oceanography should endeavour to visit the museum, which contains specimens of all types of marine life, every form of apparatus used in the investigation of the sea—even to a model of the laboratory used by the Prince and his scientific staff on their numerous cruises on his famous yacht the *Princesse Alice*. There is a permanent staff of scientists at the Station but the amount of work carried out by outside investigators is small.

In this country the largest and most important marine station is the Plymouth Laboratory of the Marine Biological Association (Plate 6) which is now one of the leading institutions of its kind in the world. This was founded in 1884 and has since then been several times extended, a special wing devoted to the study of the physiology, or functioning, of marine animals having been added only two years ago. The permanent scientific staff is larger than at any other station, consisting of a Director, seven naturalists, two physiologists, and an hydrographer, so that not only is a large aquarium maintained and the wants of the many visiting scientists, who come from all countries, attended to, but a great volume of scientific work is annually produced, much of it concerned with seasonal changes in the sea water and the contained population, work which

can only be done by a resident staff. For the collection of specimens and water samples, there is a converted steam drifter (Plate 97) and a powerful motor boat manned by appropriate crews. As many as forty workers can be accommodated in the research laboratories which are equipped with experimental tanks with circulating sea water, while on the topmost floor there is a fine library.

To describe the many other marine stations which are dotted round the coasts of Europe would be a long business. In this country, the Ministry of Fisheries has a large laboratory at Lowestoft for the investigation of problems concerned with fish and a smaller one at Conway for the study of shellfish; there are marine stations at Port Erin and Cullercoats attached to the Universities of Liverpool and Durham respectively, while in Scotland is the marine laboratory of the Fishery Board at Aberdeen and of the Scottish Marine Biological Association at Millport on the Clyde.

In spite of her sparse population, Norway has produced a great volume of valuable oceanographical research, a fact which is explained by the overwhelming importance of her fisheries. The principal marine stations are at Bergen and Trondhjem, the latter being ideally situated for research on deep water life, for the steamer attached to the station is able to dredge in the fjords to depths of over 500 fathoms. Sweden possesses a delightfully situated station at Kristineberg on the Gullmars Fjord in the Kattegat, consisting of a stone winter laboratory, a wooden one for summer use, and a number of houses for the accommodation of the staff and visitors. The Danish biological station has its headquarters at Copenhagen but the staff move about in the research steamer. The Germans possess a station well situated on the Island of Heligoland, the Dutch one at Helder at the mouth of the Zuider Zee, while

the French possess a series of stations along both the Atlantic and Mediterranean coasts of which those at Roscoff and Banyuls respectively are the most important. They have recently founded a station at Salammbô in Tunis.

Outside Europe the most important stations are in the United States where the recently extended Laboratory at Woods Hole in Massachusetts (Plate 6) is now by far the largest institution of its kind in the world; during the summer hundreds of students and research workers visit it but in the winter little is done for there is no permanent scientific staff. Near it is the laboratory of the United States Bureau of Fisheries. Other important stations are situated on the Atlantic and Pacific coasts of Canada and the United States of which perhaps the most interesting is that of the Carnegie Institution on the Tortugas Islands in the Gulf of Mexico. The development of science in Japan has led to the founding of a series of marine stations along their coasts from which valuable work, especially in connection with fisheries and oyster culture, is already being turned out.

Life in the Sea

The sea is far richer in different forms of life than the land or fresh water, many groups of animals being exclusively marine. Since many of the latter may be quite unknown to readers without special knowledge of biology, it seems advisable, before proceeding with the description of the different zones of life in the sea and the characteristics of their inhabitants, to give in this introductory chapter a short summary of the various groups of marine animals and plants.

Animals

Distinguished from all other animals, in that they consist of a single "cell," are the Protozoa. They are extremely

common in the sea ; some are minute scraps of living matter, such as the marine amœbæ, quite unprotected and moving about on the sea bottom by a kind of flowing motion ; others possess elaborate little shells of limy matter and are called Foraminifera, or of silica and are known as Radiolarians, both occurring in countless numbers in the surface waters. Others again, called Ciliates, though without shells, are of more complicated structure, being covered with fine hairs by the beating of which they move and draw in food. As widespread near the surface as the Radiolarians and Foraminifera, are the Dinoflagellates or Peridinians which have two whip-like processes for locomotion, may or may not be covered with skeletal plates, and often contain green colouring matter so that it is uncertain whether they are animals or plants.

The sponges or PORIFERA are animals of so simple a structure that they give the impression of being little more than aggregations of Protozoans. They are always attached and have a supporting skeleton, of horny matter in the sponge of commerce, but in the majority of cases consisting of immense numbers of tiny spicules of many beautiful shapes and formed in some cases of limy material and others of silica.

The CŒLENTERATA include a large number of relatively simple animals whose bodies are essentially bag-shaped, containing only one cavity which combines the functions of the stomach cavity and the general body cavity of the remaining, more highly-organized, animals. They are all built on a circular plan, i.e. there are not two symmetrical sides. They are almost entirely marine and are universally distributed. They include many common animals and may be said to be of two general types, attached like the sea anemones, and freely swimming like the jellyfish. Many of the attached kinds are not solitary individuals

like the anemones but consist of many individuals united together. Of such are the little Hydroids which have branching stems dotted with many little polyps, like flowers, each one resembling a minute anemone, which are united to one another by a common canal which traverses the stem. The framework is usually of a thin, transparent, horny material, though in a few cases it is of limy substance, the result being a kind of coral. Some of these are not attached at all, have no skeleton, and swim freely in the sea, an example being the Portuguese Man-o'-War. Allied more closely to the anemones are the false corals or Alcyonarians, consisting of many individuals with a common skeleton of thick horny substance or of tiny spicules or other material, and also the true corals (Madreporaria) with massive limy skeletons.

The worms are divided into many groups with little resemblance other than in shape. There are the little flatworms or TURBELLARIA, seldom more than an inch long, very flat and almost transparent, to which are allied many parasitic worms which, though commonly found in marine animals, need not concern us here. There are also the NEMERTINA, soft-bodied worms with a long proboscis which they can protrude or draw in at will, and without that division of the body into a series of transverse segments which is so striking a feature of the most highly-organized worms. These are known as the ANNELIDA and include the common earthworm (in which the segments we have just spoken of are very easily seen) and the bristle-worms (Polychætes) which are almost exclusively marine, being everywhere abundant and constituting the great majority of the marine worms. Besides segmentation they are characterized by the presence of long bristles which project from the sides of the body. Some wander about at will and are called errant worms, but others live always in

tubes of lime, sand or parchment-like material which they make for themselves, enlarging them as they grow and being in many cases able to make new ones if they are destroyed. Closely related are the leeches of which there are marine species which suck the blood of fish, and rather less so the Sipunculids which have a protrusible proboscis and a tough leathery body without any sign of segmentation. They are all marine. One of the commonest constituents of the drifting life of the sea is the little arrow worm, Sagitta, which belongs to a small group called the CHÆTOGNATHA, which has no connection with the other worms.

Quite closely related to the bristle-worms are the POLYZOA or sea mats, minute creatures which always live in colonies, some of which are small and branching like the hydroids, and others large and with strong limy skeletons which give them the appearance of delicate corals. In spite of their minute size the individual animals are very complex.

The ECHINODERMATA are a diverse group, exclusively marine, which include the starfish and sea urchin. Like the Cœlenterates, they are built on a radial plan though, owing to their mode of life, some have altered this and become bilaterally symmetrical. They all have limy skeletons, some consisting of continuous plates forming a compact shell as in the sea urchins, and others of isolated spicules or tubercles embedded in a leathery skin, as in the sea-cucumbers. They are in most instances either attached or very slowly-moving animals, the mechanism of locomotion being usually provided by the peculiar "tube-feet," tiny tubes which are worked by water power supplied by a series of canals within the body. There are five distinct groups, the starfish (Asteroidea) with a flat central disc to which are attached a number of arms, usually five, though it may be many more; the brittlestars (Ophiuroidea) not unlike the starfish but with the disc more

Laboratory of the Marine Biological Association, Plymouth. (p. 15).

Pl. 6. *C* 20.

Marine Biological Laboratory, Woods Hole, U.S.A. (p. 17).

On extreme left is the Fisheries Laboratory.

C'21.

Pl. 7.

The World according to Ptolemy, A.D. 150. (p. 6).

sharply divided from the arms which always number five, though they may divide and subdivide considerably, and without the groove which always runs along the underside of the arms in the starfish ; the sea urchins (Echinoidea) which are all globular, heart-shaped or disc-shaped, with a firm skeleton or shell covered with spines and usually with definite rows of tube-feet passing through , the sea cucumbers, sea gherkins or trepang (Holothuroidea) with elongated, sausage-shaped bodies traversed generally by five rows of tube-feet ; and finally the feather-stars and sea lilies (Crinoidea) usually attached and with a central disc with attachments below, and above a series of five, often branching, arms which wave about in the water.

The Arthropoda include the largest number of species of any group in the animal kingdom. Like the Annelid worms they have segmented bodies, but attached to all, or many, of the segments are the jointed limbs which give the group their name. Of the four great subdivisions, three—the Insect, Spider and Centipede families—are almost as exclusively composed of land animals, as the fourth, called the Crustacea, are marine, one of the few examples of the latter found on land being the common woodlouse. There is no space to go into the many subdivisions of the Crustacea, so all-embracing a group that it includes the tiny water fleas, the minute Copepods which drift about in countless millions in the surface waters, the barnacles which cover rocks and the bottoms of ships, the sand-hoppers of the shore, the ghost-shrimps, the true shrimps and prawns, the lobster and crayfish, the hermit crabs and the many kinds of true crabs. The greatest difference between the simpler and more complex types is that in the latter the limbs, instead of being very much alike from one end of the body to the other, have become specialized into a number of feeding limbs near the mouth,

then a group of walking legs, and finally a series of swimming legs under the tail region. Allied to them are the zoologically mysterious sea spiders or Pycnogonida, resembling the true spiders in little beyond the possession of four pairs of long legs.

The Mollusca form another great group. The Gastropoda or univalved shellfish, such as the limpets, periwinkles and snails, the great majority of which are marine (the chief exceptions are snails and slugs), have usually a shell, always of one piece, though the land and sea slugs have either no shell or else one greatly reduced and covered over with skin. Most of them live on the shore or on the sea bottom but a few, without, or with greatly-reduced shells, swim about near the surface, the sea butterflies being the commonest. The bivalve molluscs or Lamellibranchia have a shell composed of two equal, or almost equal, halves united by an elastic ligament which forces the two halves open except when they are drawn together by the powerful adductor muscles. They are all either marine or fresh-water animals, well-known examples being the mussel and the oyster. The third great division of the Mollusca includes the octopus, squid and cuttlefish, and is called the Cephalopoda. Its members are all marine and are very highly organized animals with a head having a pair of complex eyes and surrounded with a series of arms possessing suckers and hooks. Some, such as the octopus, have no shell; others, the cuttlefish is an example, have a broad "bone" down the back which is covered with flesh, while a few, like the pearly Nautilus, have a large shell in which they live.

Resembling the bivalves in the possession of a shell consisting of two valves are the Brachiopoda, usually only found in deep waters in our own seas. The two halves of the shell however, are always dissimilar, while the internal

structure of the animal is totally unlike that of the bivalve molluscs. The TUNICATA are exclusively marine and comprise many animals of very different appearance. There are the common sea squirts of our shores and shallow seas, either solitary creatures like little gelatinous or leathery bags fastened on to rocks, or else great numbers of smaller individuals embedded in a common gelatinous mass, solitary and colonial Tunicates respectively. Each individual has two openings which, when the animals are squeezed, squirt out a stream of water, hence their common name. Other varieties of Tunicates, called Salps and Appendicularians, form an important part of the drifting life of seas somewhat warmer than our own, such as the Mediterranean. They are transparent animals, which may be solitary but are often fastened together in long chains.

In their early stages the Tunicates resemble little tadpoles with a backbone which later disappears but the possession of which may mean that they are really very degenerate relations of the VERTEBRATES—distinguished from the INVERTEBRATES, which we have hitherto been considering, by the possession of a backbone. The simplest animals to show certain vertebrate characteristics are the Lancelets, like little white eels which burrow in the sand, while, rather simpler than the true fish, are the CYCLOSTOMATA, of which the lamprey is our chief example. They have a larger number of gill openings than the true fish, have round mouths with no true teeth and have no paired fins on the sides of the body.

The fish or PISCES are too well-known to need description. They are divided into two principal groups, one, called the Elasmobranchs, having a relatively soft, cartilaginous skeleton and with the gill openings separate—to mention two of their chief characteristics—and including the dog-fish, sharks and skates, and the other, known as the Teleosts

or bony fish, with the cartilage converted into bone by the presence of limy matter, and the separate gill openings covered over with a flap known as the operculum.

All animals higher in the scale of evolution than the fish are air breathers but a number have returned to the sea and spend their lives in it, some always near or on the surface but others capable of diving to considerable depths though always compelled to return to the surface from time to time to obtain air. Among the REPTILIA are the water snakes or HYDROPHIDÆ which have keeled bodies and tails flattened like those of fish to aid them in swimming, and the turtles which are aquatic tortoises with the limbs flattened to form swimming paddles. In the MAMMALIA there are the many kinds of whales, dolphins and porpoises which constitute the Cetacea and spend their entire lives in the sea, an existence for which they are just as well equipped as the fish themselves, and also the strange sea cows (Sirenia), sluggish, harmless beasts which usually live in shallow water near the mouths of rivers in tropical regions and frequently sit on their tails with only their heads out of water—the origin, probably, of all the stories about mermaids! Finally there is a group of the Carnivores (which include the lions, tigers and bears) the members of which, exclusively marine, except in the breeding season, are known as the Pinnipedia and include the seals, sea lions and walruses.

Plants

The sea is far poorer in types of plant life than the earth. The flowering plants have very few marine representatives, the best known being the eelgrass (*Zostera marina*) which is widespread in sheltered regions round our coasts. The great majority of marine plants are Algæ, of simpler structure than the flowering plants and reproducing them-

Calcareous algae, Corallina and Melobesia; and Limpet *(Patella vulgata)* × ½. (pp. 31, 32).

Pl. 8. C 24.

Smooth Blenny *(Blennius pholis)* × ⅔. (p. 36).

Pl. 9.

Smooth Winkle (*Littorina obtusata*) (p. 32) on **Bladder Wrack** (*Fucus vesiculosus*) $\times\frac{3}{4}$. (p. 30).

C 25.

Above: **Channelled Wrack** (*Pelvetia canaliculata*).
Below: **Flat Wrack** (*Fucus platycarpus*). (p. 30).

selves by " spores " instead of seeds produced by flowers. We may divide them into two types, fixed and drifting. The former are the sea weeds and may be further divided into four groups each of which has a characteristic colour as well as structure. There are (1) the Blue Algæ (Cyanophyceæ), (2) the Green Algæ (Chlorophyceæ), (3) the Brown Algæ (Phæophyceæ), and (4) the Red Algæ (Rhodophyceæ) ; these are found from high-water mark downward into deep water in the order named, ; this is discussed in more detail later. The first-named are of slight importance, they are minute plants which sometimes form a slimy film over rocks, but many of the others are of considerable size, the Brown Algæ including, not only the strange floating Sargassum weed which gives its name to the Sargasso Sea in the Gulf of Mexico, but also the largest known plant in *Macrocystis pyrifera* with fronds 200 yards long which is found off the southern parts of South America. Since plants demand a certain minimum of light, all trace of weed disappears from the bed of the ocean below a certain depth. The deepest water from which weeds have been taken with any certainty that they were actually growing on the bottom appears to be about 60 fathoms, but normally they are not found abundantly except in shallow water.

The drifting plant life, apart from the large Sargassum weed, consists of minute single-celled plants called diatoms which have tiny silica cases, and also the Peridinians which, as stated above, can be considered either plants or animals as they have certain characteristics of both. Both occur in untold billions and are of primary importance in the economy of marine life.

CHAPTER II

The Sea Shore

THAT narrow strip between the high and low-water marks of spring tides which we call the sea shore is the haunt of a rich and varied collection of plants and animals and has, on account of its unique position at the junction of sea and land, an interest altogether out of proportion to its area. Many books have been written about the sea shore and its inhabitants, for the subject is a big one and teeming with interest, but in this volume with its wider scope we can only devote one chapter to it and endeavour to give some general idea of the many fascinating problems it presents. Those who are sufficiently interested are advised to seek further information in the books recommended at the end of this volume.

The extent of shore uncovered at low tide naturally depends on the sharpness of slope, and this depends on a variety of factors, the nature of the land, its configuration and the action of the tides, currents and rivers, being the most important. Anyone who has lived near the sea knows how in some places the outgoing tide uncovers great areas of mud or sand, while in others, with a quickly descending shingle beach, only a comparatively small area is uncovered at the lowest spring tides. It has been estimated that the total area between tide marks in Great Britain and Ireland amounts to some 620,000 acres. We can distinguish between three types of shore, formed of rock, sand or mud, though these may be mixed to a greater or less extent.

The waves are the greatest influence at work moulding the shore, breaking with fury against the land, washing away loose material or, with the aid of pebbles and stones which they dash against it, gradually eating into a hard, rocky coast, forming a flat "abrasion platform" at the base often of towering cliffs. Here we find a typical rocky shore. In other regions, on the other hand, the action of powerful cross currents deposits great banks of sand, formed by the breaking down of rocks. At the mouths of rivers or in sheltered creeks and gulleys there are mud flats where the sediment brought from land is deposited. The action of ice and of weathering in general also assists in the wearing away of the land and the formation of the shore, while the influence of plants and animals is not to be neglected. The former often help to bind together sand and mud and convert them into firm, dry land; encrusting animals, such as barnacles and mussels, may help to protect rocks, but usually the action of animals is destructive, notably that of the various rock borers.

A feature of the greatest importance is the variability of conditions on the shore. Not only does the sea cover and uncover it twice daily, but the ranges of temperature are far greater, both yearly and often daily, than in any other part of the sea. An animal in moderately cool water at high tide may be left stranded at low tide in a small rock pool where the temperature rises to great heights under the influence of a hot summer sun. The shallow water near the shore is both warmer in summer and cooler in winter (when ice may form on the shore) than the deeper water further out. The constitution of the sea is also apt to be variable, especially near the mouths of rivers where much fresh-water is mixed with it; also in the height of summer when, in enclosed areas, evaporation may make the sea more than usually salty. The influence of light is very great, greater

than in any other region except the surface waters of the open sea. This has an immediate effect in the distribution of plant life, for plants can only exist where there is light which is necessary for the "photosynthetic" action of their green pigment by means of which the carbonic acid gas in the atmosphere, or in solution, is combined with water to form starch, which, with the addition of salts obtained from the soil or from solution, forms the food of the plant. The influence of this flora of sea weeds on the life of the sea shore is of great importance.

The population of the sea shore if it is to withstand these very variable conditions must be extremely hardy—how hardy we realize when we discover that very slight changes in the temperature or salinity of the water will kill animals used to the uniform conditions of the open ocean. The animals must be adapted in many different ways, for protection, food collection, and reproduction, to mention only three of the most important. Yet in spite of these difficulties the population of the sea shore is one of the densest and most varied on the surface of the earth. So dense, indeed, that the most striking features of shore life are the perpetual struggle for existence, the constant scramble for food in which the strongest or most subtle are the conquerors, innumerable devices for ensuring the continuance of the race, the never ceasing pursuit by the more powerful of the weaker and smaller, the latter surviving to the extent to which they are able to disguise or hide themselves.

We can distinguish very definite associations of animals living on the shore. By this we mean that in different sets of conditions we habitually find the same types of animals, perhaps varying in species from place to place. These animals may be of many different kinds—some of them worms, others starfish, crustaceans, molluscs and so on—but they are all adapted for life under those particular conditions; they may

Acorn-barnacles *(Balanus balanoides)*, $\times \frac{3}{4}$. (p. 31).

Pl. 10. C 28.

Periwinkles *(Littorina littorea)*, $\times \frac{1}{2}$. (p. 31).

Starfish *(Asterias rubens)* **and young Mussels** *(Mytilus edulis)*, × ¼. (p. 32).

Pl. 11. C 29.

Crumb-of-bread Sponge *(Halichondria panacea)* **and Beadlet Anemone** *(Actinia equina)*, × ½. (p. 32).

all be plant feeders and live on weed, they may all be attached forms and live fastened to rocks, or be burrowers into mud or sand, or they may be carnivorous beasts which prey upon the animals composing one of these communities to which they thereby become attached. The most intimate form of association is that of parasite and host (as we call the animal which " entertains " the parasite), or the more equal type of intimate union known as symbiosis, some account of which is given on page 213. Lastly, animals, without being actually united with one another, may always live together, one perhaps upon the other, a condition called commensalism, because the two feed in common and also frequently assist one another. Examples of this are given later in this chapter.

We can recognize a series of fairly definite zones as we pass down from high-water mark over the shore at dead low water. On rocky shores we can distinguish these zones by the different levels at which the principal sea weeds grow. The different coloured weeds have a perfectly definite arrangement, the green ones generally growing in pools near high-water mark or even above it where sea water only occasionally penetrates and the water is largely fresh; the brown weeds are especially common between tide-marks, as no one who has ever walked on a rocky shore can fail to have realized, while below them come the red weeds. These are usually found between tide-marks at the bottom of the deeper rock pools or when the spring tide uncovers an exceptionally large area, but are commonest in shallow water off a rocky shore.

Above high-water mark, except at the highest spring tides, there is an area of mixed salt and fresh water—brackish is the term used to describe it—which, if the ground be marshy, is usually characterized by the presence of the little salt-wort, a tiny plant (not a sea weed) which has

become adapted to these conditions ; if the shore is rocky and there are pools in this region they are filled with the green weed, Enteromorpha, consisting of long tubular fronds. In the summer the pools are apt to dry up, the weed is killed and only a line of white marks this Enteromorpha belt. About the region of high-water mark there is a belt, in breadth from a few feet to about five yards varying according to the slope of the shore, of the yellow or olive coloured " Channelled wrack " (*Pelvetia canaliculata*), distinguished from the other brown weeds by its narrower fronds. (Plate 9.) From the base of this belt to low-water mark the rocky shore is covered with a tangle of brown weeds known generally as the fucoid zone, because most of the weeds are members of the genus Fucus. The various kinds of Fucus are arranged in quite a definite series. Next to the Pelvetia comes the broad fronded *Fucus platycarpus*, followed by a broader belt of *Ascophyllum nodosum* or " Knotted wrack," with exceptionally long fronds bearing a single row of bulbous air bladders down the centre. This weed is easily to be distinguished because on it invariably grows a small red weed (*Polysiphonia fastigiata*). The next belt consists of *Fucus vesiculosus* or " Bladder wrack " (Plate 9), to be distinguished by the pairs of air bladders along the fronds which, when dried, " pop " sharply when pressed. Nearest low-water mark is the commonest and most strongly growing of all these fucoids, *Fucus serratus*, the " Notched wrack " which, as its name tells us, has toothed serrations along the edge of the fronds. These different belts of Fucus are not always present, depending on local conditions, the amount of fresh water, exposure, etc., while there are several less common species which we have not mentioned, but generally speaking the above types will be found on any typical rocky shore. They are terminated, quite sharply, at low-

water mark by a broad belt composed of several kinds of Laminaria, the largest of the brown weeds which has long fronds, very broad and without a mid-rib, and is secured to the rocks by a massive "hold-fast." They are never exposed except at the lowest spring tides.

A number of other weeds are common on the shore, and can most conveniently be referred to now. The green weeds are especially widespread, the "Sea lettuce" (*Ulva lactuca*) with broad, delicate fronds and living in pools usually above half-tide level, and *Cladophora rupestris* of a darker green and bushy compact growth which is common in pools everywhere. An easily recognized brown weed commonly exposed between tide-marks is *Himanthalia lorea*, which has peculiar cup-shaped attachments to the long narrow fronds, while of the red weeds, the "Dulse" (*Rhodymenia palmata*) which has flat, irregular crimson fronds, and "Carragheen" (*Chondrus crispus*) (Plate 127) with thicker dark reddish-brown fronds, which appear blue when seen in certain lights, are the commonest, occurring in the upper and lower regions of the shore respectively. The latter is eaten in certain parts of Ireland. Frequent in rock pools are the pink encrusting corallines (Plate 8), not at first easily recognized as sea weeds for they have limy skeletons like some of the encrusting animals.

Now let us consider some of the animals which live on rocky shores. They may be divided roughly into four categories, those which live exposed on the surface of stones, rocks, or weeds, those found under stones, those which live in holes and cracks in the rocks, and those inhabiting rock pools. Of the first group the most characteristic members are the sessile acorn-barnacles (*Balanus*) which cover the rocks with a carpet of little sharply pointed pyramids, especially near high-water mark where they form a definite Balanus zone (Plate 10). Here too are many

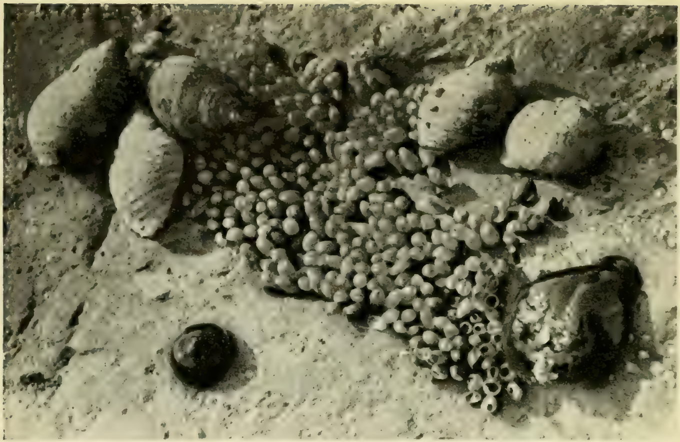
marine snails, of which the common limpet (*Patella*) and the periwinkles (*Littorina*) (Plate 10) and the top-shells (*Gibbula* and *Calliostoma*) are the commonest; they browse upon the weeds and corallines which cover the rocks. The limpets (Plate 8) have definite "homes" on the rock face to the surface of which their shells are exactly fitted so that, when disturbed, they can, by pulling down the shell, fix themselves so firmly that very great force is needed to disturb them; it has been estimated that limpets with a basal area about one square inch need a pull of seventy pounds to remove them. In all directions around can occasionally be seen radiating paths cleared of weed showing where the limpet has foraged for its food. There are a variety of periwinkles which live in different regions of the shore, one (*L. rudis*) always living very high on the shore, often where it is untouched by sea water for weeks together, the common winkle (*L. littorea*) lives lower on the shore always on rocks, while the smaller and less pointed species (*L. obtusata*) which varies greatly in colour from black to white, is always found on the fronds of fucus. Resembling the winkles but rather larger and with a thicker shell is the dog-whelk (*Purpura*), which inhabits the upper half of the shore (Plate 13), preying upon the limpets or smaller top-shells. Other peculiar animals allied to the snails are the chitons of which our largest species are about an inch long and about half as wide; they are flattened, with the shell arranged in eight parts each slightly overlapping the one behind, and when pulled away from the rocks on which they browse, they curl up like little armadillos. There is a numerous population growing on the weeds, notably many kinds of hydroids, sea mats and small snails.

Nearer low-water mark we find the rocks covered with sponges of which the "crumb-of-bread sponge" (*Halichondria*) is the commonest (Plate 11), forming a dense mass

Golden Stars Tunicate *(Botryllus)*, $\times\frac{1}{2}$. (p. 33).

Pl. 12. C 32.

Gooseberry Sea squirt *(Styelopsis grossularia)*, $\times\frac{3}{4}$. (p. 33).



Dog-whelk *(Purpura lapillus)* **laying eggs ;** below : **two closed up Beadlet Anemones** *(Actinia equina)*, $\times\frac{2}{3}$. (pp. 32, 50).

Pl. 13. *C* 33.

Sea slugs (*Lamellidoris bilamellata*) **depositing their egg ribbons,** $\times\frac{1}{2}$. (p. 37).

which may be several inches thick and vary in colour from a pure white in shaded places to a yellow or green in more exposed situations. The deep crimson Hymeniacidon is often found with it. A common sponge which is attached by a stalk is the purse sponge (*Grantia compressa*), often found on the sides of rocks where there is no danger of it being dried up, and there are other kinds of sponges too numerous to describe. Growing on rocks or fucoid fronds is the tiny worm Spirorbis, which lives in a flat spiral shell like that of a snail and often occurs in great numbers. Larger worms with limy tubes of irregular shape (Serpulids) are frequently common on rocks. Frequently covering rocks are found sea squirts, especially the compound forms—consisting of colonies of simple individuals—such as the golden-stars Tunicate (*Botryllus*), which closely resembles a sheet of purple jelly dotted with tiny golden stars (Plate 12) though some simple sea squirts are found, especially the Gooseberry (*Styleopsis grossularia*), a little reddish lump well described by its common name, and abundant near low-water mark (Plate 12). Other encrusting animals are the sea mats or polyzoa, which form, with the sponges, sea squirts, coralline weeds and other algæ, a dense carpet over the face of the rocks. Finally about low-water mark we may find bivalve molluscs such as the saddle-oyster (*Anomia*), the common mussel (*Mytilus edulis*) and one of the smaller scallops such as *Pecten varius*. These are attached in different ways, the saddle-oyster being permanently attached by its shell and adhering very closely to the surface of the stone while the mussel and scallop are secured by tough threads known as " byssus " the formation of which is described on page 304.

A fresh fauna is revealed when we begin to turn over loose stones. Near high-water mark there is a varied collection of small crustaceans and insects. Of the former the largest

is the flat Ligia, sometimes an inch and a half long and closely resembling the common woodlouse ; this is everywhere abundant and runs about, especially at dusk, usually just above high-water mark, for it is a beast which is by no means dependent on sea water, a slight moisture being apparently all that it needs. Associated with it are a number of sand-hoppers (*Talitrus*, *Orchestia*, *Gammarus*) which, when a stone or pile of dried weed is moved, go jumping away in all directions. Unlike Ligia, they are flattened not from above below but from side to side, a characteristic which separates the group of crustaceans to which they belong, the Isopods, from the Amphipods. The insects include some beetles, but especially the little spring-tails. Lower on the shore, where the tide always reaches, are found a great variety of worms, such as Nemertines, of which the most conspicuous is the long " boot-lace worm " (*Lineus*) usually tied in a tangled mass which is almost impossible to disentangle without breaking for it may be many yards long. There are also tiny flat-worms which move like semi-transparent films over the surface of stones or on the under side of the surface film in pools. Here we find great numbers of the more highly organized bristle-worms, examples of which are the bright green *Eulalia viridis*, which is common all over rocks, and the yellow *Cirratulus cirratus* which lives in patches of sand or mud beneath the rocks with only its filamentous tentacles to be seen. Still more worms are found nearer to low-water mark, the commonest being perhaps the handsome *Nereis diversicolor*, of varied colours and six inches or more in length. It is frequently used as bait, being known as " rag-worm " in many parts. A variety of little worms, broad and flattened with two rows of large scales on their backs, known as Polynoids, are common everywhere.

Of the numerous crustaceans the largest and commonest

is the common shore crab (Plate 16), Carcinus, of which examples scurry away from beneath almost every stone we examine. Common also is the velvet fiddler crab (*Portunus puber*), one of the largest of the swimming crabs, a very pugnacious beast, aptly called by the French fishermen "*Le Crabe Enragé*," also a great variety of smaller crabs of varying shapes and habits, far too numerous to mention here. Some spider crabs are found, but they are commoner off shore and will be described in the next chapter. The curious little green squat-lobster (*Galathea squamifera*) may be mentioned (Plate 14), while occasionally left behind by the tide near low-water mark are small lobsters or edible crabs (Plates 14 and 113). Hermit crabs provide one of the quaintest and most characteristic members of the shore fauna. Unlike the other crabs, they have no shell covering the tail region but creep for protection within the empty spiral shells of molluscs holding firmly on to the central column of the shell by means of claw-like appendages at the hind end of the body. They are able to shuffle about quite rapidly carrying the shell, which they can, however, leave if they wish to, a procedure which becomes essential as they grow larger and have to forsake the old shell for another a size bigger. The peculiar little sea spiders, which have long legs and such thin bodies that the stomach for want of space has to penetrate the legs, are found under stones. Starfish are commonly met with near low-water mark, especially the large red *Asterias rubens* (Plate 11), and, more difficult to see, the little "Cushion-star" *Asterina gibbosa* of a dull grey or greenish colour which lives on the sides of rocks. Both of these have five arms but those of the latter are much shorter relatively, and are united for almost their entire length. Their relatives the sea urchins especially the small green *Echinus miliaris*, which is a more typical shore form than the handsome *E. esculentus*

(Plate 15), are also inhabitants of rocky shores. They are covered with spines—which in allied animals from warmer seas may be of great length and, sometimes, thickness—and must be handled carefully.

Some shore fishes can always be found under stones. The most common is probably the butterfish (*Centronotus gunellus*), about six inches long, eel-like, flattened from side to side and with nine or more dark spots edged with yellow down the middle of the back. The smooth blenny (*Blennius pholis*) (Plate 8), can withstand long periods out of water and is common on the shore, as are the bullhead or father-lasher (*Cottus bubalis*), with its large head armed with four formidable spines, the five-bearded rockling (*Motella mustela*) to be recognized by the five barbels under its snout, and various kinds of sucker-fish (*Lepadogaster*), whose hinder (pelvic) fins are united to form a sucker by means of which the fish fastens itself to rocks.

In holes and cracks in rock live worms of various kinds, also a quaint crustacean called Gnathia and the little sea gherkins (*Cucumaria*), which can frequently only be removed by splitting the rock with a crowbar. Here, too, are rock-boring bivalves, especially the common Saxicava, though the large " Piddock " (*Pholas*) and some of its smaller allies are common in some parts.

There is no more fascinating or more beautiful spot on the shore than a typical rock pool. Its sides and bottom are usually covered with a many-coloured carpet of weeds, sponges, hydroids, sea mats and sea squirts, amongst which, like flowers, glow the rich colours of anemones (Plate 16). The commonest of these—by no means confined to the pools but common on the higher parts of shore—is the beadlet (*Actinia*), usually a deep red or brown, but sometimes red with green spots (the strawberry variety) or, less frequently, a bright green. At the base of the tentacles is a row of blue

spots. The largest of the anemones is the handsome dahlia (*Tealia*), with a warty column unlike the smooth one of Actinia, and of many colour patterns, some of them strikingly decorative. This also is not uncommon on the shore at the base of rocks, but usually nearer low-water mark. Especially common in the pools is the "Snake-locked anemone" (*Anthea cereus*)—appropriately so named for it has long tentacles which wave with the motion of the water and, unlike those of the other anemones, are incapable of contraction. We must pass by many of the other anemones, mentioning only the beautiful little Corynactis very common in some regions, no bigger than a pea and of many colour-varieties, pink, green and white ones being found. Other inhabitants of rock pools are hydroids, of which the handsome Tubularia is the finest, a variety of tube-dwelling worms of which the most conspicuous is Bispira, with its wide parchment-like tube and yellow crown of tentacles in the form of two spiral whorls united at the base, many snails especially the conspicuous sea slugs, such as Æolis (Plate 17), with its back covered with a "fur" of soft grey projections, the sea lemon (*Doris*)—also very common on rocks everywhere (Plate 17)—and a great number of smaller kinds. Crustaceans abound, especially prawns, both the large Leander and the little Æsop prawn (*Hippolyte*), so difficult to see because of its remarkable power of colour change.

A sandy shore has a very different population. Both sea weeds and encrusting animals are absent for there is no hard surface to which they can attach themselves. Many of the sand dwellers are burrowers, spending all or part of their lives beneath the surface, maintaining contact with the water in a variety of ways. The predominant animals are bivalve molluscs, of a type which do not attach themselves permanently like the mussel or the saddle-oyster,

but can move about and burrow by means of a " foot "—a muscular organ, usually wedge-shaped, which can be protruded from between the two halves of the shell and by its sudden movements enables the animal to progress by a series of jerks on or beneath the surface of the sand. Amongst the commonest of these are the cockle (*Cardium edule*), which lives near the surface, several species of Venus, one of the clams, which have ridges round the somewhat globular shell the better to enable them to grip the sand, and a number with more flattened shells, such as Tellina, Macoma, Gari and the beautiful, highly-polished Donax, all of which live deeper down than the cockle. The long razor-shells (*Solen*) may occasionally be dug at low tide ; in it the two halves of the shell form a cylinder with the two ends open, the lower one enabling the foot, and the upper one the two siphons concerned with the circulation of water and the supply of food, to be protruded.

Worms there are in plenty, usually with a delicate, coloured ring of tentacles round the head end. They live buried with only these tentacles exposed for the capture of their fine food, withdrawing them on the approach of an enemy or when the tide retreats. Of such are the Terebellids, to be recognized by their sandy tubes the upper ends of which, fringed with fine filaments, project above the surface, also Amphitrite (Plate 77), a fine red worm with a bush of sinuous tentacles. Other worms of a carnivorous habit, such as Nephthys, are found, while, commonest of all, is the lug-worm, Arenicola, whose castings are so common dotted over the sandy shore (Plate 18). Like the earth worm on land, it spends its time swallowing the sand in which it lives, passing it out in the form of the familiar castings. The head of the animal lies at the bottom of a small depression and the mouth continually draws in sand which, since the burrow is usually U-shaped, is conveniently disposed of

Squat-lobster (*Galathea squamifera*), × ½. (p. 35).

Pl. 14. *p.* 38.

Edible Crab (*Cancer pagurus*), × ⅓. (pp. 35, 73).

Sunstar (*Solaster papposus*). $\frac{1}{2}$. (p. 66).

Pl. 15. *P* 39.

Sea urchin (*Echinus esculentus*) under water. $\frac{1}{4}$. (p. 35).

on the surface. It is extremely abundant in suitable localities, such as the shore round Holy Island where a population of 82,000 per acre has been estimated. An animal which might be easily taken for a worm is the reddish Synapta, also found in sand, which is really a relative of the sea cucumbers. Allied animals—in structure, not appearance—are the burrowing sea urchins (*Echinocardium*) (Plate 20), to be dug near low-water mark, though, as we shall see, they are commoner in deeper water.

It is on such sandy shores that the common shrimp (*Crangon vulgaris*) is found, though it is difficult to see owing to its sandy colour and its habit of covering itself with sand, leaving only the long feelers exposed. With it are a variety of other crustaceans, notably the ghost-shrimps (Mysids), smaller and even more difficult to see. There are several kinds of crustaceans which construct burrows often of great depth so that considerable industry is needed in digging them. Several anemones habitually live buried in sand with only the mouth disc with the surrounding tentacles exposed. Where reefs of rock run out into the sand we frequently find large colonies of the peculiar reef-building worm Sabellaria (Plate 18), a creature which forms a sandy tube not in, but above, the sand, and not singly but in great numbers altogether, so that large reefs of hardened sand are formed which, on examination, will be found to be honeycombed with the tubes of the worms which construct them. Various fishes are common in shallow water on sandy shores, being occasionally left behind in pools by the retreating tide ; of such are young flat-fish of various kinds and the sand-eel (*Ammodytes*).

We may consider the associations found in mud and in estuaries together because the mouths of rivers are the great site of mud deposition. The fauna bears many resemblances to that found on sand, with which the mud

is frequently mixed, burrowing forms being by far the commonest. Thus, of the bivalves, the large "gaper," *Mya truncata*, is the most conspicuous, it possesses a thick shell—some three times the size of the mussel—which has a permanent gape at the hind end where the long, muscular siphons project (Fig. 4). Another characteristic type is Scrobicularia, to be recognized by its extraordinarily flattened shell and by the length of the siphons which, unlike those of the gaper, are free from one another. Where the mud is intermingled with stones the large horse-mussel (*Modiolus*) is common. Worms are abundant, especially burrowing species, and those living in tubes; of these the common *Sabella pavonia*, with its parchment-like tube and widely spread ring of red and white plumy tentacles, and *Myxicola infundibulum*, with its thick gelatinous tube and shorter, more compact tentacles, are the commonest. The former often occurs in such numbers that at low water the tubes, of which usually some five inches project above the surface, appear like a little forest. Of anemones, the brown *Sagartia bellis* is the commonest. There are a variety of crustaceans including the ubiquitous scavenging shore crab. Estuaries and creeks with a mixed bottom of mud and stones often harbour oysters, which are fastened to the stones and with these are found their invariable enemies, the boring dog-whelks, Nassa and Murex and the common starfish, *Asterias*

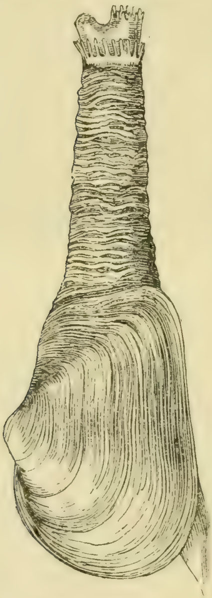


Fig. 4.—The Gaper (*Mya truncata*), ($\times\frac{1}{2}$).

rubens. A variety of prawns and also sticklebacks penetrate far up rivers, being apparently indifferent to the change from salt to fresh water—a barrier which effectively prevents the great majority of shore beasts from passing up estuaries.

We have dealt with the plants and animals of the sea shore, very briefly, it is true, but in sufficient detail we hope, to give some idea of their variety and of the different types found under different conditions, and it is now time to consider the many peculiarities of the shore beasts and the particular devices they possess to enable them to live and propagate their kind in the strange section of the earth's surface which they have chosen for their home.

Methods of Attack and Defence

Of the first importance are means of attack and defence. Purely mechanical weapons are not particularly common and are best exemplified by the powerful pincer-like claws of the larger crustaceans, especially lobsters and crabs. In the former the two pincers are never quite alike and if a lobster be examined it will be found that one of the claws is larger with rounded, irregular teeth—clearly adapted for crushing—and the other slenderer with numerous sharp teeth and is used for cutting. There is no regular arrangement of these claws which may occur on either side; they are immensely strong and, in the case of the shore crab, have been found capable of supporting a weight equal to about thirty times that of the body, whereas a man's right hand when clenched is unable to support a weight equivalent to that of his own body! Poison is largely used, especially by the anemones and hydroids and all their allies, which possess batteries of stinging cells, the action of which is described on page 203. All over the

surface of the shell of sea urchins are little clawed spines, of various patterns, but usually with three teeth which can open and snap together. These are used to clean the shell, removing any fragment of waste matter, but also for protection, for if an enemy attacks an urchin the long spines on that side turn away exposing the smaller clawed spines beneath, which snap at any part of the enemy touching them, and also produce a poison which passes into the wound.

More universal are methods of passive defence. The thick shell of the crustaceans and of the univalve and bivalve molluscs are examples. The last-named are frequently safe so long as their shell can be firmly closed and the two muscles concerned with this—the adductor muscles of the shell—are extremely powerful, though very variably so in different beasts, those of the cockle for example having less than a quarter the power of those of Venus. How the bivalves may be successfully attacked and eaten by whelks and starfish we shall see in Chapter IX. The hermit crabs have found an excellent means of protection by using empty mollusc shells. Then there are the various devices whereby an animal escapes attention by toning with the background. This may be done by having a colour similar to the surroundings—one particular set of surroundings or any surroundings, the animal in the latter case changing its colour to tone with the background. This is particularly common in small crustaceans and flat-fish on the shore. The vivid colours of many sea slugs, which are unable, however, to change colour, usually tone with those of the rocks or weed on which they live. Many spider crabs "mask" themselves by deliberately decking their shells with pieces of weed or sponge which continue to grow there. The dahlia anemone and the smaller sea urchin both cover themselves with stones and pieces of shell.

In all these cases we must remember that the concealment is not only from foes but also from the prey, i.e., for attack as well as defence. For protection alone are the limy, sandy or parchment-like tubes of the worms, while the borers probably find the interior of stone or wood safer than a more exposed habitat.

The replacement of lost parts of the body is a very familiar occurrence on the shore. Crustaceans have an almost unlimited power of growing new limbs. It is quite common for them to be faced with the alternative of sacrificing one or more limbs or else losing their lives.

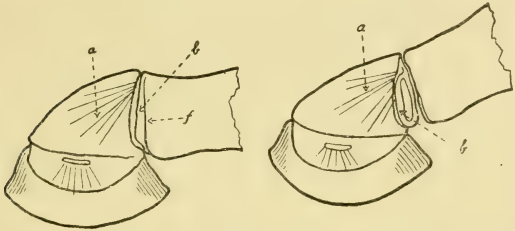


Fig. 5.—Diagram to illustrate breaking plane of Crustacean limb; *a*, muscle responsible for breaking; *b*, detached ring of third segment of limb; *f*, breaking furrow (after Paul).

They do not hesitate to do the former and the limb is cast off at a special line of weakness called the "breaking plane," the fracture being caused by the deliberate contraction of the muscles at this point (Fig. 5). Owing to the depth of the furrow, the wound is small and blood quickly coagulates and closes the opening. So the animal remains, with a stump in place of a limb, until the next time it moults, when the rudiments of the new limb force their way out quickly before the new shell has had time to harden. At each successive moult the process is carried a little further until the new limb is as large as those which were uninjured.

This habit of *deliberately* parting with limbs which are later regenerated is called " autotomy," and is not confined to the crustaceans, being widespread amongst the starfish and their delicate allies, the brittlestars. Both of these part with their arms very readily and quickly grow new ones; they may lose all their arms and yet from the central disc there will grow out a complete new set (Fig. 6).

The related sea gherkins have the more unique power of casting up their viscera when disturbed or attacked, then proceeding at their leisure to grow new ones. It may well be that, under normal conditions, the attacker is satisfied with the meal of soft entrails thus provided, and will not trouble their owner further. The worms have exceptional powers of regeneration and when cut in two accidentally—or by design in the laboratory — will grow new heads or tails with equal facility. Sponges have probably the most remarkable powers in this direction, for a sponge can be broken into tiny fragments which are then strained through fine meshed silk, and yet the isolated pieces will come together and unite to form new individuals !

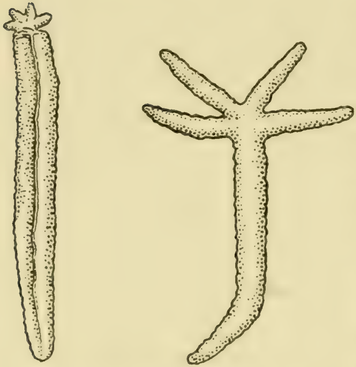


FIG. 6.—Starfish regenerating arms. Two stages in regeneration of new arms from a single severed arm (adapted from Flattely and Walton).

We are leaving a consideration of parasitism and of the intimate, mutually advantageous union of two animals or an animal and a plant, known as symbiosis, to Chapter IX, but we must say something here of that looser form of

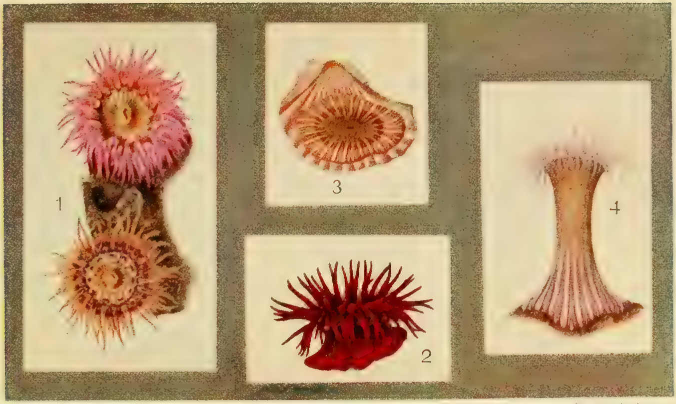
association called "commensalism," which may be defined as an external partnership between two different animals usually for their mutual benefit. On the shore the most striking example is furnished by the association between the hermit crabs and different kinds of anemones and sponges. One species of hermit, *Eupagurus prideauxi*, is always found with its body enfolded by an anemone, *Adamsia palliata*, which resembles a sausage-shaped bag pushed in at either end, to form, at the upper end the stomach cavity, the mouth of which is surrounded by tentacles, and at the lower end the much larger cavity occupied by the soft body of the crab. A mollusc shell is always present in the first place and to this the crab is attached. The common shore hermit, *E. bernhardus*, which lives in shells of all sizes up to those of the whelk, usually carries on the shell a large anemone, *Sagartia parasitica*, while in the upper whorls of the shell there is often a worm called Nereilepas. Yet a third, smaller hermit, *E. pubescens*, is often almost obscured by the relatively large masses of a sponge which almost invariably grows on the shell. This definite association between the hermit and the anemones and sponge is clearly not accidental, in the former case the anemone probably helps to protect the hermit which, in turn, provides the anemone with scraps of food, in the latter case the sponge may provide protection by camouflage and itself receive food.

Other examples of commensalism are provided by the gall crabs which live in coral. The young female crab settles down between two branches of the coral, which as a result, broaden and finally unite above the crab, forming a gall within which the crab lives, feeding, not on the coral, but on particles brought in by the water. The male of the species remains outside the coral. The pea crab, which lives in bivalves and sea squirts, is a further example.

Another is furnished by a tropical crab (*Melia tessellata*), which carries anemones in each of its claws, first deliberately removing them from the rocks. It holds them fully expanded, pushing them forward when attacked and taking out the food they capture and transferring it to its own mouth. The claws are used exclusively for carrying the anemones. The advantage to the crab is obvious while the anemone, in spite of losing so much of its food, perhaps gains, as by being moved about in this manner it has so many more opportunities of obtaining food.

Adaptations for Breathing

The problem of respiration—of obtaining that essential minimum of oxygen, without which no animal can live—is often serious on the shore, where the inhabitants are part of the time in water and the remainder in air. We have not space here to discuss the different organs, or gills, used in different animals for obtaining oxygen, but some instances of shore animals which are able to respire both in air and in water will be of interest. This can be done, in a sense, by a variety of animals which are able to keep their gills moist for considerable periods while out of water, for example, the crustacea, which have gills covered over by the edge of the shell—as in the higher forms like the lobster and crabs—or in the form of plates beneath the body. Of the different periwinkles, those which live nearest the shore and are often out of water for long periods, have developed the power of breathing air, the walls of the gill cavity having become richly laden with fine blood vessels whereby the blood is able to take up its oxygen from the air. There are crabs which live exclusively on land, some, such as the tropical robber crab, only going to the sea to breed, and having developed a true lung for breathing, while others which have retained their gills have to go down to the sea



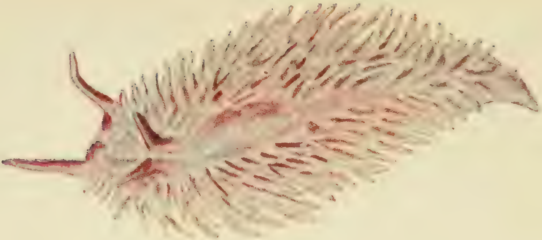
DEL. I. A. S.

Sea Anemones. (p. 36).

1. *Sagartia elegans.* 2. *Actinia equina.* 3 & 4. *Sagartia viduata* (closed and expanded).

Pl. 10. *P.* 40.

Shore Crab (*Carcinus maenas*) **casting shell,** × 1. (p. 53).



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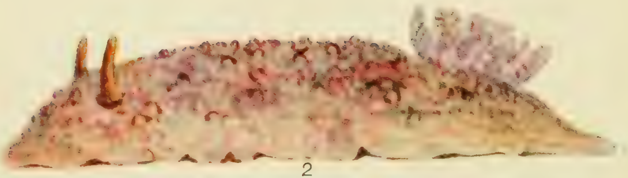

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Pl. 17. DEL. E.S.R. *p.* 47.

Sea Slugs.

1. *Eolis papillosa.* 2. *Doris tuberculata.* 3. Spawn of Doris on a Sea squirt. (pp. 37, 50, 51). Natural size.

occasionally in order to moisten them. There are also species of tropical fish, notably the "walking goby," which are able to live out of water and even to climb trees; they have a lung-like extension of the gill chamber, while it is also reported that they breathe through their tails, for they sit on the land with only their tails in water! If held under water for any length of time they are drowned.

Locomotion and Migrations

As we have seen, many shore animals are attached to rocks or weed or else live in permanent tubes or burrows. The advantage of this mode of life is clear when we consider the perpetual beating of the waves on the shore as the tide comes in and goes out. Of equal advantage is the burrowing habit of many animals, bivalve molluscs and burrowing sea urchins, for example, which are also able to move about beneath the surface. Movement in shore animals takes many different forms. The larger crustaceans clamber over rocks and through gullies by means of their strong, hinged walking legs. The starfish move steadily over the surface by the concerted action of the many tiny "tube-feet" each terminated by a small sucker, double rows of these feet lining the grooves which run down the centre of the underside of the arms. They are connected with a complicated system of canals containing water which can be forced out of or into the tube-feet at will, enabling them in turn to fix and relax their hold. A similar mode of movement is found in the sea urchins, which also employ their teeth for this purpose! A mussel may move up the side of a rock by fastening a byssus thread as far as possible above it and then pulling itself up by hauling on to it. Some shore fish, such as the blennies, can crawl over rocks by means of their fins. The shore insects and the crustacean sand-hoppers move by jumping, suddenly straightening

out the tail or hind end of the body. Periwinkles, whelks and all their allies really glide over the surface, waves of movement passing over the broad flat "sole" of the large fleshy "foot." Anemones and flatworms glide in a similar manner. Apart from the fish, many animals swim, the lobsters by sudden movements of the tail which propel them quickly backwards through the water, while many worms are able to swim to a greater or less extent by undulatory movements of the long body, some, most highly specialised, having paddle-like flaps on the side of the body. Mention will be made of the swimming crabs and of the

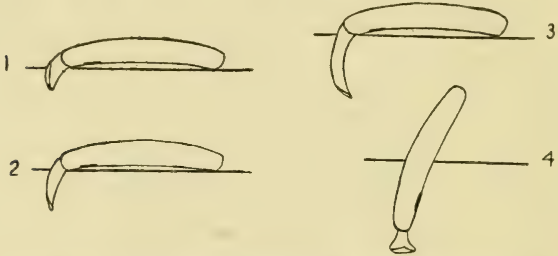


FIG. 7.—Razor-Shell (*Solen*); 1-4 showing successive stages in burrowing in sand (after Fraenkel).

swimming scallops in the next chapter. The peculiar movements of boring animals are discussed in Chapter VI. The burrowing bivalves work their way through the sand by the action of the muscular foot, the most specialised case being that of the razor-shell, which drives its pointed foot directly downwards, anchors it there by forcing in blood which makes the end swell out and then, by a sudden contraction, draws the shell down to the level of the foot, repeating the process as often as need be and burrowing so quickly that one has to drive a spade in very suddenly to capture it (Fig 7.). Burrowing worms, crustaceans

and sea urchins all have special devices which enable them to work their way through the sand or mud.

Many fishes migrate long distances, usually because their feeding and spawning grounds are far apart. There are also migrations on the sea shore, though on a much smaller scale. The movements of edible crabs have been studied, and it has been found that they move from near the shore into depths of twenty or thirty fathoms about the beginning of autumn and remain there until February, when they begin to return to the shore again. The eggs are laid in the winter in deep water and remain attached to the body of the female, finally hatching out during the summer in the warmer water near the shore. Both temperature and food, therefore, play a part in determining the yearly travels of the crab and also of lobsters and prawns which, though we know less of their habits, appear to migrate in a similar manner. The shore fishes also move into deeper water in the winter, while many of the bigger sea slugs, such as the Sea Hare (*Aplysia*) and the large Plume-bearer (*Oscanius*) come on to the shore during the summer specially for spawning. Attention has already been drawn to the more localised movements, apparently concerned with feeding only, of the limpets, and this habit is also found in allied beasts.

Spawning

In such a difficult region as the sea shore, spawning has to be carefully attended to if the race is to be continued. Spring and early summer are the times usually chosen for spawning, for the water is then teeming with microscopical plant life, which forms ideal food for the newly-hatched young. We may divide shore animals into three classes according to their methods of reproduction ; those which discharge their reproductive products freely into the sea where they float helplessly until swimming organs are

developed; those which deposit adhesive spawn on to stones, sea weed or empty shells; and those in which eggs and developing young are attached to the body of the parent. In the first division are the sea urchins, starfish, brittlestars, many worms, barnacles and the bivalve molluscs. Since the chances of destruction are excessively great, the number of eggs shed is correspondingly large, a striking example of which is supplied by one of the larger American oysters, which is said to produce 100,000,000 eggs annually! If a sea urchin or mussel be watched when spawning, it will be seen to discharge a cloudy fluid which, on microscopical examination, will be found to consist of incredible numbers of eggs or sperm. Yet so great are the dangers to which these unprotected young are exposed that the race does no more than hold its own!

If search be made among the rocks during the spring, many kinds of spawn will be found. Common on the under side of rocks are the egg-capsules of the dog-whelk (Plate 13), which look like grains of corn, and are attached by short stalks, occurring in groups of fifty, a hundred or even more. Each consists of a tough case, containing a number of developing embryos, amongst which there is the keenest competition, the weaker being eaten by the stronger, so that finally only the one or two strongest emerge. The sea slugs provide the most diverse and ornamental spawn, covering the rocks with ribbons of jelly, often beautifully coloured, in which lie embedded the developing eggs. The common sea lemons (Plate 17) lay their eggs in a broad band of pure white, always arranged in a triple coil, some fifteen inches long and about one inch wide, the margin being unusually wavy. Over half a million eggs may be laid in a single ribbon, for the young hatch out at a very early and unprotected stage. The spawn of other sea slugs shows other peculiarities, some consisting of spirals

with up to ten whorls, the edges of the ribbon being scalloped or the whole zig-zagged in its course, and usually white or yellow in colour (Plate 17), though that of the common Æolis is pink and ropy.

The eggs of the crustaceans are usually carried by the female—either in special chambers on the under side of the body called "brood pouches" or, in the more highly-organized crabs, prawns or lobsters, attached to the swimming legs—until the early stages of development have been passed, which may take several months, so that the young leave the parent, not as defenceless eggs or embryos, but as actively swimming "larvæ," a full account of which is given in Chapter V. A crab or lobster which is "in berry" is probably familiar to everyone, and shows this condition clearly. In the sea spiders the male carries the eggs, which are handed over to him in a bundle by the female as soon as they are laid.

The effect of different conditions on the spawning of shore animals is very strikingly shown by the spawning habits of the different kinds of periwinkles. The kind which lives nearest low-water mark lays its eggs in little capsules from which the young hatch out at a very early stage as tiny swimming creatures; the young of the periwinkle which occurs about the middle of the shore hatch out at a later stage though still requiring water to swim in, while those of the periwinkles which live near, or even above, high-water mark are produced as miniature editions of their parents, and able to crawl about on exposed rocks at once. These differences are connected with the increasing lack of water, for the earlier the stage at which the periwinkles are hatched, the longer they will need water in which to swim before they settle down on the shore.

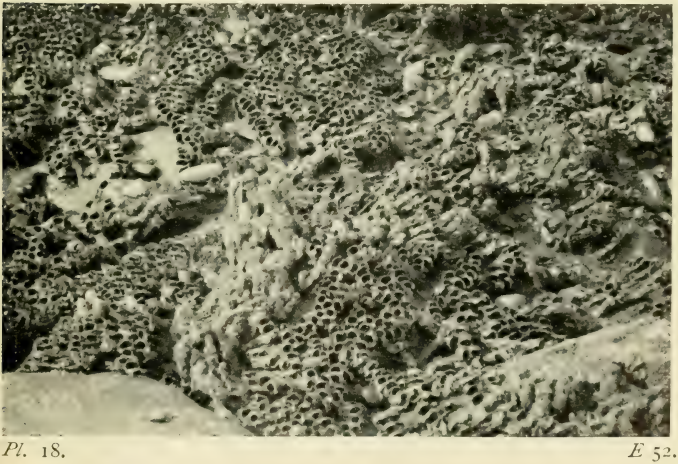
Not all animals reproduce themselves sexually. Some bud off pieces of themselves, divide in two or break up into

fragments, each of which grows into a new individual. The anemones, although some kinds habitually reproduce themselves sexually, often divide (a process which is highly developed in the reef building corals, as described in Chapter VII), or break off small fragments near the base. The little syllid worms break up in a perfectly definite way into fragments of a few segments, each of which grows a new head at one end and a new tail at the other, and so develops into a full-sized worm. The hydroids have a complicated history. They produce not eggs but little jellyfish, called medusæ, which swim about near the surface of the sea and, when fully developed, produce eggs which develop into the hydroids which produce the medusæ. This, in common with the production of swimming young by various shore animals, is of great importance in securing the distribution of animals which, because of their slowness of movement or fixed mode of life, would not otherwise be able to spread far from their original home.

Growth

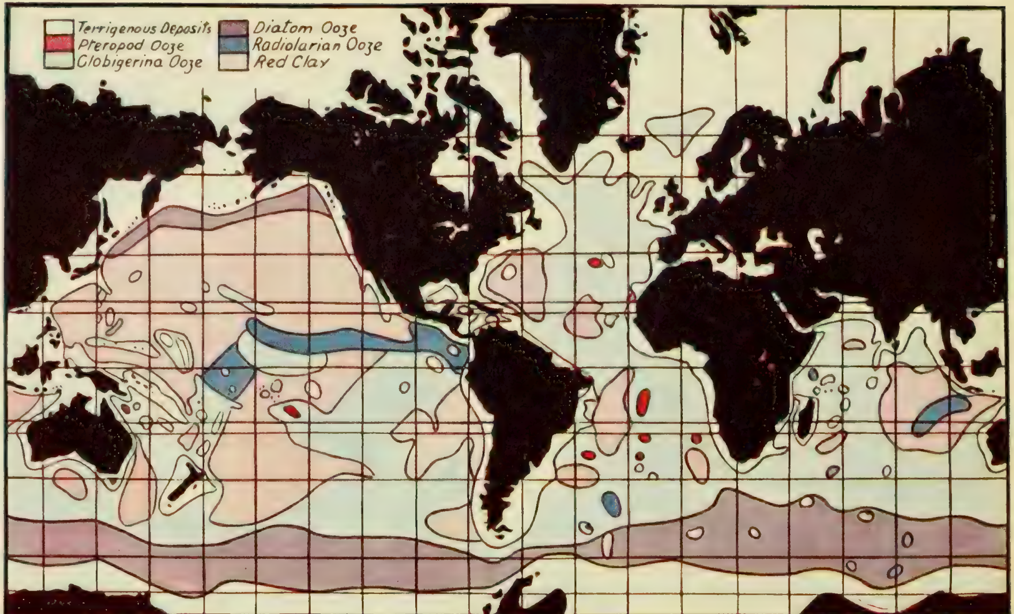
Length of life in shore animals varies within the widest limits. Some animals, such as many sponges and sea squirts, are annuals or even go through several generations in a single summer, whilst on the other hand anemones may live to a great age ; there are some in captivity known to be over sixty years old. After the early embryonic or, in the case of animals with swimming young quite unlike their parents, " larval " stages, most animals assume the adult shape changing in size only as time goes by. Growth is usually a steady process, varying in speed according to the time of the year, being generally slower in winter and quicker in summer when it is warmer and there is more food. In the crustaceans, however, growth takes place by a series of jumps. Unlike the molluscs, which increase the

Casts and holes of Lug-worm *(Arenicola marina).* (p. 38).



Pl. 18. *E* 52.

Portion of a reef of sandy tubes of *Sabellaria alveolata.* (p. 39).



Pl. 19. E 53.

Chart showing bottom deposits. (p. 55).

shell by adding to the free edges, or the sea urchins, which increase theirs by adding new plates in between those already formed, the crustaceans are unable to add to the shell and have to cast it and form a new one (Plate 16). These moults take place at regular intervals, depending on the particular beast and on the prevailing conditions, the entire shell being cast—not only that which protects the body but the covering of the limbs and even the lining of the stomach and hinder part of the gut! The animal withdraws itself, often with obvious difficulty, from its old shell and is then left soft and completely defenceless, until the new one has formed and hardened; this, however, takes place very quickly, for the substances of which it is formed have been stored up in the skin beforehand. The new shell is always larger than the old one, the animal seizing this opportunity to "grow" to the size it would have attained if the hard shell had not prevented its increase.

This must end our brief survey of the animals and plants of the sea shore.

CHAPTER III

The Sea Bottom

Bottom Deposits

Before we discuss the animals which inhabit the bed of the ocean at different depths and in different zones, we must first say a little about the nature of the deposits which cover the bottom, in or on which the animals live. The study of these deposits formed the greater part of the life-work of the famous Scottish oceanographer, Sir John Murray, who was one of the scientists on the *Challenger* expedition. It is to him that we are indebted for the bulk of our knowledge on this subject, for, as a result of his exhaustive study of samples collected on that expedition and on later expeditions, he was able to classify the ocean deposits into a series of groups which later research has completely confirmed.

Broadly speaking, there are two types of bottom deposits. There are those formed by the settling of material washed down from the land by rivers or worn away by wave action, which Murray called Terrigenous deposits and which are found in deep and shallow water near the land. The only regions where this type of deposit is found any great distance from land is opposite the mouths of the greatest rivers, such as the Amazon, which brings down great quantities of material in suspension which the strong current of the river carries far out to sea. It might be thought that material in suspension would not sink readily in the

sea, but this is not so because, as a result of the mixing of the fresh water with the sea, the fine particles become attracted electrically to one another and so form large masses which readily sink just at the region of mixing of the fresh water and the salt.

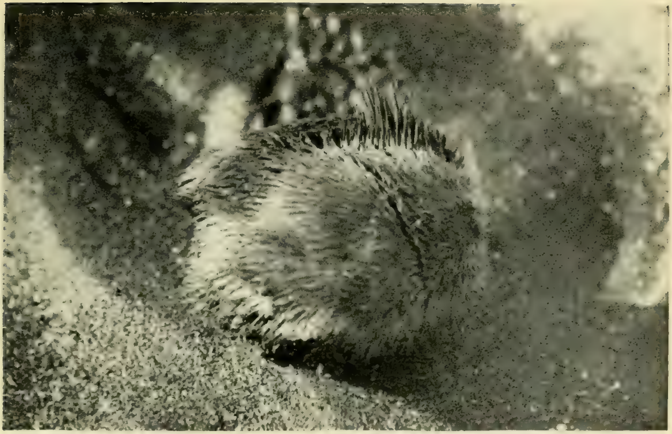
At about 100 fathoms the action of waves and of transporting currents ceases to be effective, and below this line, which is called the mud-line and corresponds roughly to the continental edge, the particles come to rest permanently and from this region outwards the bed of the ocean is covered everywhere with mud. Terrigenous deposits are found both above and below this line, depending on its nearness to land, and their nature naturally corresponds to the nature of the land from which they are derived. Between tide marks and in shallow waters they consist of sand, gravel, shingle and boulders with mud in sheltered areas, rather further from the shore are gravel, sands, banks of living and dead shells, and, especially opposite estuaries, banks of mud. If the land is volcanic this is reflected in the volcanic nature of the deposits, if of coral origin the deposits are formed of finely divided coral while, off continents, the deposits are usually quartz gravels and sands together with marls. The terrigenous deposits beyond the mud-line were divided by Murray into five categories—blue, red, green, volcanic and coral muds, the first three varying somewhat in their chemical content but having much in common while the nature of the last two is clear.

In areas far from land the deposits on the sea bottom consist exclusively of material which has dropped down from the surface waters. This second type of marine deposit has been called Pelagic by Murray (Plate 19), and is made up of volcanic dust which has fallen on to the surface of the water from the air, or of dead animals or plants which, as they die, rain down upon the bottom far below.

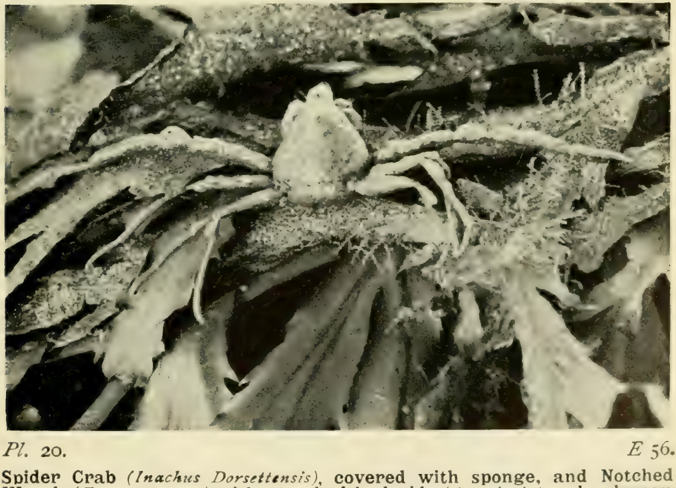
The vast bulk of life in the open sea is composed, not of large and active creatures, such as fish or whales, but of microscopic plants and animals which drift near the surface and make up the all-important plankton. It is their skeletons which form the great proportion of the deep-sea deposits, for their bodies soon disintegrate or are eaten by other animals. From their consistency Murray called these deep-sea deposits Oozes, and distinguished them according to the complete absence or relative abundance of the various kinds of skeletons.

Particularly around the poles, in the Antarctic ocean especially, the surface waters contain vast numbers of the microscopic plants called diatoms, each individual of which is enclosed in a delicate case of silica, and it is these minute plant " skeletons " which form the chief constituent of the deposits in these regions, hence called diatom ooze. Although there is an abundant flora in the temperate and tropic seas, there is a larger proportion of animals, those with calcareous shells being the commonest. Chief among these are the tiny foraminifera of which one called Globigerina is the most plentiful, and ooze, with its limy skeletons as the principal constituent (Plate 21), is extremely widespread covering an estimated area of some 48,000,000 square miles, being especially abundant in the Atlantic. A third type of deposit which is really only a variety of the last is called Pteropod ooze ; it takes its name from the predominance in it of the limy skeletons of delicate swimming snails known as Pteropods or " sea Butterflies " which are commonest near the equator where this type of ooze is exclusively found, always in shallower water than Globigerina ooze and especially near coral islands and on submerged elevations far from land.

Beneath a certain depth oozes with limy shells as their principal constituent are no longer found, all calcareous

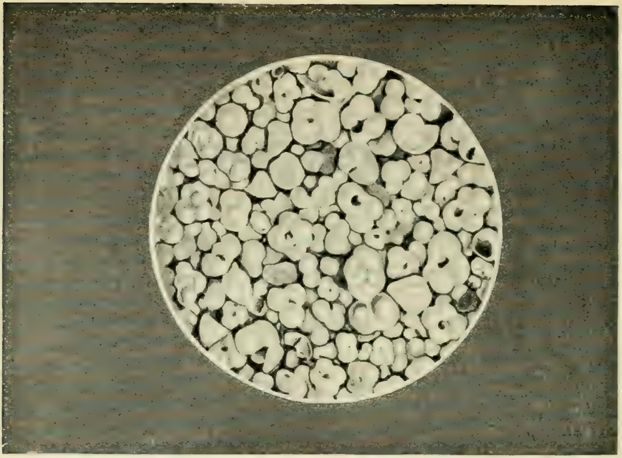


Heart Urchin *(Echinocardium cordatum)*, $\times \frac{2}{3}$. (pp. 39, 63, 66).

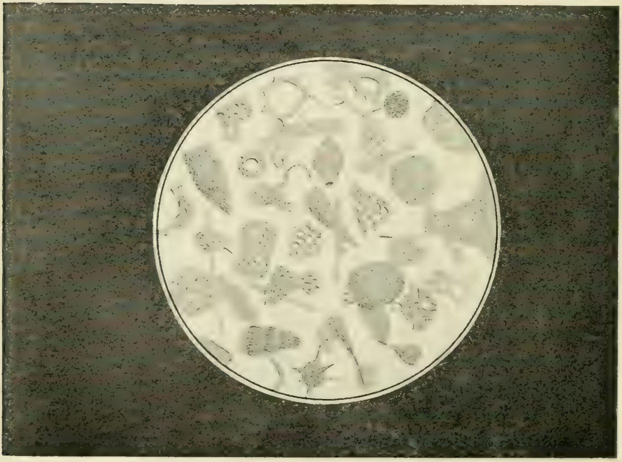


Pl. 20. *E* 56.

Spider Crab *(Inachus Dorsettensis)*, **covered with sponge, and Notched Wrack** *(Fucus serratus)* **with attached hydroids** *(Sertularia)* **and polyzoan** *(Alcyonidium)*, $\times \frac{2}{3}$. (p. 63).



Globigerina Ooze. (pp. 56, 118).
Magnified.



Pl. 21. E 57.

Radiolarian Ooze. (pp. 57, 118).
Magnified.

matter having been dissolved away on its passage downward through the water. In certain areas, notably in the tropical regions of the Pacific and Indian oceans, there are great numbers of minute animals known as Radiolarians in the surface waters; these have skeletons of silica, often of very beautiful lattice design, which form the most conspicuous part of the deep-sea ooze in these regions (Plate 21). Finally, at the greatest depth of all (below 2,700 fathoms) even the silica is dissolved and the deposits then consist exclusively of what Murray called "red clay." This is a true clay which has been formed by the prolonged action of the sea water on volcanic dust which is all that has survived the long journey from the surface to the bottom. Like the siliceous deposits it is present at all depths but is usually masked by the deposits of animal or plant origin. In this red clay are found spherules probably of meteoritic origin, and also the completely insoluble teeth of sharks—some of which belong to extinct species—and ear-bones of whales.

Although the actual substance of the sea bottom has not the same overwhelming importance as the soil on land, since even the sea weeds do not root in it, merely attaching themselves to rocks, and obtain all their nourishment from the substances in solution in the water, yet it has considerable importance. In the first place it is of use to the bottom living animals which may crawl on its surface, burrow into it, or attach themselves to it. The nature of the bottom—sand, mud, gravel or rock—is of the first importance to them. In the second place the deposits form a reserve of substances of which the sea can only carry small quantities in solution, but which are of vital importance in the economy of marine life. Of these lime and silica which, as we have seen, form the skeletons of the great mass of animals and plants, and manurial salts, such as phosphates and nitrates, produced by the decomposition of dead animals, are the

most important. If there were not a constant reserve of these in the bottom deposits, the sea would soon become denuded of them ; as it is the amount of silica, to take but one example, in solution near the surface is greatly reduced in the spring and early summer when the diatoms are increasing most rapidly. In the winter when the diatom flora is reduced and there is a mixing of the waters at various depths and a fresh dissolution of silica from the bottom, the surface waters become fully charged with silica ready for the demands of the coming spring.

Life on the Sea Bottom

The animals which inhabit the bottom of the ocean are called the benthos, to distinguish them from the drifting and actively swimming animals known as plankton and nekton respectively. Extensive investigations by means of dredges and trawls have shown that the benthos varies greatly in different regions both in quantity and quality. Generally speaking animals are most numerous in coastal waters, and become less and less so the further we pass from the land into deeper water, though there is animal life, and often of a unique and interesting kind, even in the abyssal regions with red clay deposits. The greatest number of different species is found in the tropics, especially around continents and in the neighbourhood of coral islands, but the temperate and polar seas make up for the paucity of variety of species by the far greater numbers of individuals of those kinds which occur there.

Differences in fauna are chiefly the result of differences in depth, temperature, salinity and food, and of the interactions of these factors. The influence of the last is universally felt, that of salinity is apt to be local, the result of currents or great influxes of fresh water from rivers, that of temperature is especially effective in the shallower waters near the coast

and changes in temperature are primarily responsible for the great differences in the faunas of tropical, temperate and polar regions—differences in the "horizontal" distribution of animals. Temperature and depth are the factors of greatest importance controlling the "vertical" distribution of animals from the shore into deep water. Owing to the decrease in temperature, the horizontal differences become less and less as the water gets deeper, thus we find similar animals at great depths in the polar and equatorial regions because the temperature is the same, while animals found in shallow water in temperate seas, for example, have relatives living in deeper water with a similar temperature in the tropics.

The shallow waters of the globe can be divided into different regions corresponding to changes in the horizontal distribution of animals, the result, as we have seen, of differences in temperature. These, it must be noted, do not follow parallels of latitude, but are greatly influenced by cold and hot currents, an example of which is provided by the western coasts of Europe bathed by the warm Gulf Stream and the frozen coasts of Labrador—in similar latitudes—which are washed by the cold Labrador current. We can distinguish between an Arctic region, including the water round the North Pole and "boreal" areas along the west coast of Europe and in the North Pacific ; an Indo-Pacific Region including the shores of India, East Africa, China, the East Indies and Australia ; a West American Region along the tropical shores of West America ; an East American Region running southward from Newfoundland ; a West African Region including both the Mediterranean and the Guinea coast ; and finally an Antarctic Region which includes the southern coasts of Australia, Africa, and South America from the Argentine on the east to Ecuador on the west. Within any one area the members of the marine

fauna have much in common. The fact that a number of animals from the Arctic and Antarctic regions are closely akin has led to the development of the theory of "bipolarity," which states that the animals inhabiting these cold seas are more closely related to one another than they are to the animals inhabiting the warm waters which stretch between them. It is thought that they maintain connection by way of the cold deeper waters of the tropics. It may, however, be that the animals from the two polar regions which resemble one another are both descended from the same deep-water animals of intermediate regions which found their way into shallower water at both ends of the earth.

Since it is impossible for us to describe all the multitudinous bottom animals which make up the different horizontal zones or faunas, we must confine our attention to giving a general account of vertical distribution with examples taken from our own seas. It is convenient to divide the sea bottom into various areas; the first, called the Littoral zone, extends from the shore to about twenty fathoms; the Sub-littoral or Shallow Water zone extends to 100 fathoms; from the continental edge down the slope to a depth of some 500 fathoms there is a Continental Deep-sea zone; while, finally, there is the Abyssal zone.

Littoral Zone

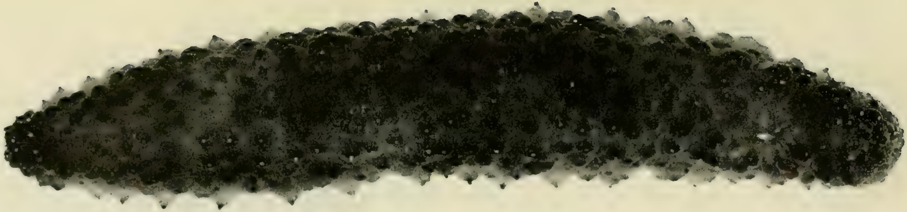
In the previous chapter we discussed the animals of the shore which are, strictly speaking, part of the littoral fauna. There are, however, five areas coming immediately below low-tide mark—the fringes of which are usually exposed during spring tides—each of which has a distinct population; namely, the Laminaria belt, Zostera belt, hard bottom, sandy bottom and muddy bottom.

In the first of these, characterized by veritable forests

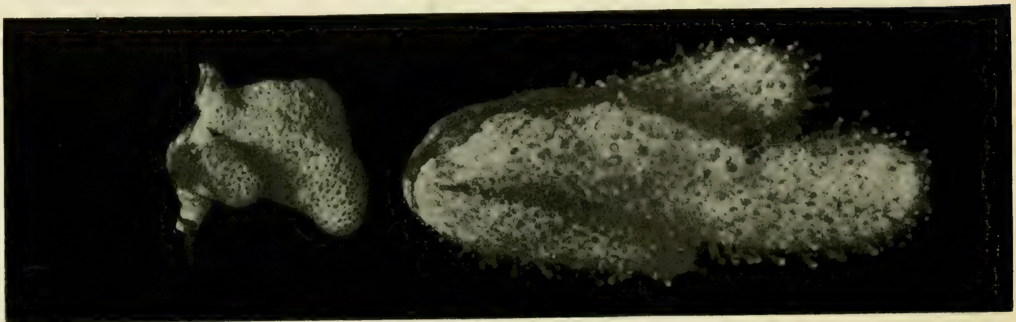
Laminarian zone uncovered at extreme low water of spring-tides *(Laminaria digitata)*. (p. 61).

Pl. 22. *E* 60.

Sea Mat *(Membranipora membranacea)* **on frond of Laminaria,**
ca. natural size. (p. 61).



Sea cucumber *(Holothuria nigra)*, $\times\frac{1}{2}$. (p. 64).



Pl. 23. *E* 61.

Dead-men's-fingers *(Alcyonium digitatum)*. Left: Polyps contracted. Right: Polyps expanded. $\times\frac{2}{3}$. (p. 62).

of tangled Laminaria (Plate 22), a large population lives attached to the weed, among the most common of which are sea mats especially *Membranipora membranacea* (Plate 22) which forms a delicate latticed encrustation with typical rounded outlines where the colony is actively growing over the surface of the frond. Many hydroids are found, their branching stolons ramifying over the surface, the branches bearing the feeding polyps projecting freely into the water. A little limpet (*Nacella pellucida*), distinguished by the blue stripes on its shell, is invariably found browsing on the bulbous hold-fasts of the Laminaria. A great assemblage of animals find a home in this region, many of them so small as not to be discovered without great care ;

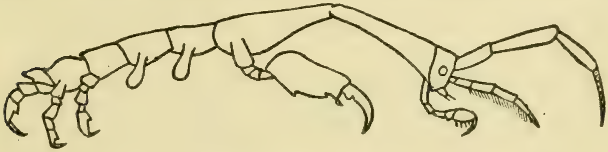


FIG. 8.—Ghost-shrimp or Caprella ($\times$ 5).

there are small sea slugs which feed on the hydroids and sponges, and many little mussels, worms, snails and starfish, some of which spend their entire lives here and others only their early phases. In the hold-fasts of the weed are worms and one of the boring bivalves, Saxicava. Perhaps the most interesting of the many crustaceans are the grotesquely elongated Caprellids, or ghost-shrimps (Fig 8), which are especially adapted for climbing about on weeds and hydroids, being provided with grasping claws at either end of the body by means of which they progress rather like a "looping" catterpillar.

Zostera or eelgrass is only found in sheltered pools and estuaries usually rooted in mud, for it is a true grass, not a

sea weed, and has roots for absorbing nutriment from the soil. In some parts of the Kattegat and in the lagoon-like Limfjord in Denmark, it covers vast areas. The associated fauna is not very rich ; a little snail called Rissoa is very plentiful and this is also the haunt of the beautiful green Haliclystis best defined as a little, squarish jellyfish, which crawls about on the eelgrass. This is the home of fish such as sticklebacks and pipe-fishes, the latter, which have long, slender, brown or green bodies, being very difficult to see against the dead and living blades of eelgrass. They swim in an upright position by the vibration of the delicate dorsal fin, coming to rest in the same position and swaying with the motion of the water. Closely related to them is the quaint sea horse. A number of snails lay their egg capsules on eelgrass, on which, however, there are few encrusting animals.

A large and characteristic fauna is found on hard bottoms in the Littoral zone. There are many attached animals, notably sponges, sea mats, hydroids, sea squirts and corals, the latter including "Dead-men's-fingers" (*Alcyonium digitatum*), consisting of dead-white, finger-like growths covered with tiny polyps (Plate 23), and the little solitary coral, Caryophyllia, which is almost our only example of a true "stony" species. Serpulid worms, which live in limy tubes and have little plugs for closing the opening when the plumose tentacles are withdrawn on the approach of an enemy, are common and also a variety of molluscs like the saddle-oyster, whelk, chiton and, of special interest, the delicate bivalve, *Lima hians*. This has a fringe of long orange tentacles which cannot be withdrawn within the shell, but float in the water and make it the most beautiful of bivalves. It has the interesting and very unusual habit of living in a nest which it constructs out of pieces of stone and shell bound together with fine threads. Sea urchins are

found here, also the common brittlestar, Ophiocoma (Plate 24), and many starfish such as *Asterias rubens*, and *A. glacialis*, a related larger, grey species, though these latter wander far in the pursuit of food. In cracks and holes live the sea gherkins, their whitish bodies hidden, and only the tentacles exposed. There is the usual abundance of crustaceans, such as the lobster (Plate 113), and many crabs, including the edible species and several spider crabs (e.g. *Inachus*, *Hyas*, *Macropodia*) which have delicate limbs and disguise themselves with pieces of weed fastened to small hooks on the shell, and so survive in spite of their weakness. Prawns of various kinds are always to be found among rocks.

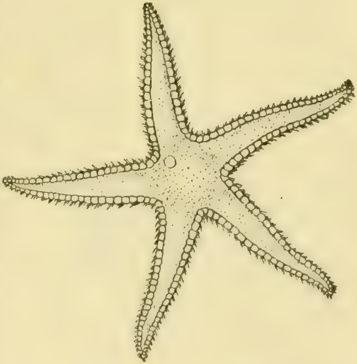


FIG. 9.—Astropecten.
A Starfish which burrows in sand (× ½).

Burrowing animals are the characteristic members of the sandy-bottom fauna. The burrowing bivalves are too numerous to mention. The common cockle is never found, but the spiny cockle—a larger species with its shell covered with powerful spines, the better to enable it to grip the sandy gravel—takes its place. Associated with the bivalves are carnivorous snails which bore into and feed upon them. Burrowing sea urchins, such as Echinocardium (Plate 20) and Spatangus, and the little heart-urchin, Echinocyamus, live in sand, and also one starfish in particular, named Astropecten (Fig. 9), which has pointed instead of sucker-like tube-feet. It burrows in sand, capturing and swallow-

ing small bivalves. Several kinds of worms habitually live in sand, while of crustaceans the commonest are the swimming crabs, which have the terminal joint of the fifth pair of legs flattened and paddle-shaped, enabling them to swim upwards. Especially adapted for a buried existence is the masked crab, Corystes (Fig. 10), which lives with only the extreme tip of its long, upwardly directed feelers exposed. Each of these has two rows of stiff hairs which, when the feelers are placed together, interlock so that a channel is formed down which water can be drawn. Other devices for obtaining water for respiration while burrowing are the long siphons of the bivalves, and the rows of vibrating spines which keep up a circulation of water through the burrows of Astropecten and the burrowing urchins.

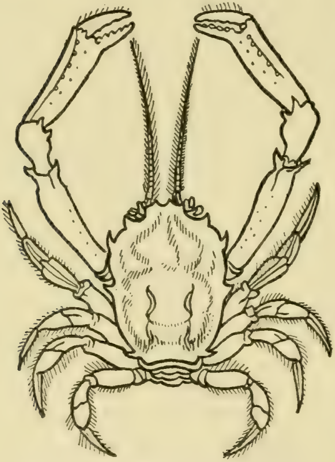
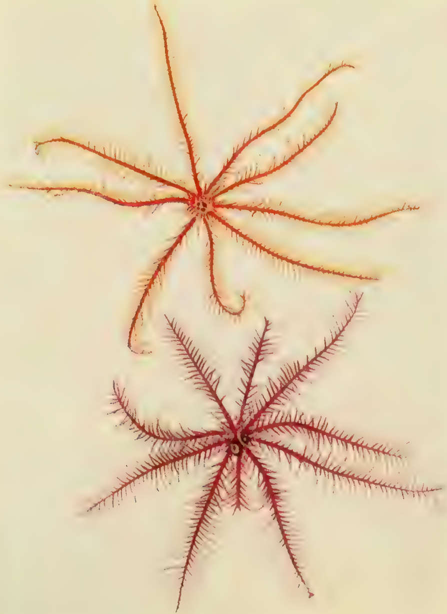


FIG. 10.—The Masked Crab, *Corystes*, which lives in sand (slightly reduced).

Burrowers are also typical of a muddy bottom. There are anemones of which only the mouth and tentacles appear above the mud, a variety of worms which burrow or live in parchment-like tubes and also scavengers like the interesting sea mouse, Aphrodite, which attains a length of six or seven inches and has a broad back covered with mouse-coloured felting beneath which are scales, while from the sides of the body spring clusters of spines and beautiful iridescent hairs. The big sea cucumber or trepang (*Holothuria*) (Plate 23), lives chiefly in mud

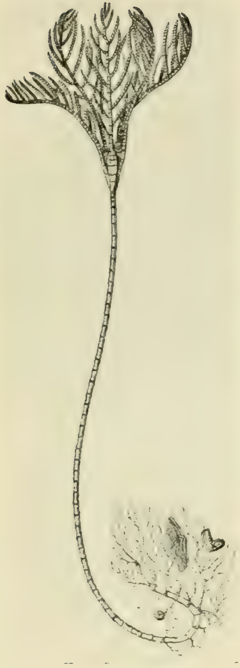


Pl. 24. E 64.

Brittlestar *(Ophiocoma nigra).* $\times\frac{1}{2}$. (p. 63).

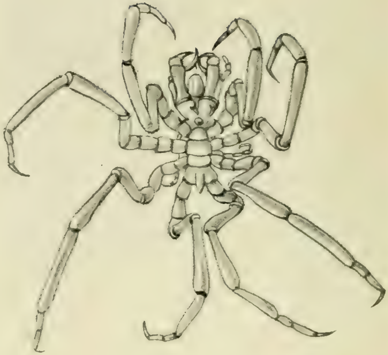
Feather-stars *(Antedon bifida)* $\times\frac{1}{2}$. (p. 66).

Pl. 25. *E* 65.



Sea Lily.

(*Rhizocrinus lofotensis*), $\times\frac{3}{4}$.
(p. 71).



Sea Spider.

(*Nymphon robustum*), $\times\frac{2}{3}$. (p. 71).

attaining to a length of a foot and a diameter of three inches, and has a thick brown or yellowish skin. It moves, like its relatives the starfish, by means of five rows of tube-feet, and has the curious habit, when irritated, of shooting out masses of sticky white threads, which swell up greatly in water and completely incapacitate attacking animals. Because of this habit, it is also called the cotton-spinner. On greater provocation it ejects its stomach and entire viscera, later growing a fresh set. Crustaceans are not especially common in mud but a number of small species are found.

Shallow Water Zone

Many of the animals just mentioned, and also a host of others, are also found in the Sub-littoral or Shallow Water zone, for these two regions contain as dense and varied a population as any on the earth's surface. The bottom is usually soft, of sand, mud or muddy clay frequently mixed with stones and rocks which, together with hosts of empty shells, furnish a foundation for the attached animals. We can here only refer to a few of the commonest or more interesting inhabitants, some of which are also found in shallower water, for the boundaries we make are largely artificial. Carnivores and animals which feed on particles in suspension—animate or inanimate—or swallow the bottom mud and sand, are especially abundant for, though light penetrates, if the water be clear, to depths of 100 fathoms or even more, it is insufficient to support plant life in depths considerably less than this. Down to sixty fathoms, however, there is frequently an abundance of the limy coralline weeds or Nullipores, of which the commonest, Lithothamnion, forms an important constituent of the sea bottom in many parts.

Representatives of the Foraminifera, which live in limy shells often consisting of a series of chambers spirally arranged, are amongst the smallest members of the bottom fauna. On hard surfaces grow great masses of sponge, such as the yellow Clione and Desmascedon, which produces endless amounts of slime so that when it is put in a bucket of water the whole becomes thick and sticky. Many crustaceans and worms burrow into these sponges or shelter in the crevices. On muddy bottoms the most striking inhabitants are the sea pens, creatures allied to the anemones and hydroids, but consisting of a main, central stem from the upper half of which spring branches bearing tiny polyps, the whole being distinctly reminiscent of a quill pen. Thick growths of hydroids and miniature forests of the beautiful pink coloured gorgonids or sea fans (Plate 26), the numerous branches of which extend all in the one plane, like a fan, are both found on rock or stones. Here also live the beautiful Crinoids or feather-stars (Plate 24), another group of the starfish family, which hold on to the bottom by means of a series of outgrowths from the under side of the body, while their ten delicate, foliaceous arms wave about in the water above. They begin life attached, like the sea lilies of which we shall speak later, but afterwards break off and swim with graceful movements of their arms. The British representative is red, brown or yellow in colour and one of the most beautiful members of our marine fauna. Many brittlestars and a variety of starfish, such as the fifteen armed purple and rosy sun-stars (*Solaster*) (Plate 15), the red cushion-star (*Porania*) and the large yellow Luidia occur in different localities, while burrowing urchins (Plate 20) and sea cucumbers are found on soft, and sea gherkins on hard, bottoms.

Amongst the many worms are included burrowers in

mud such as the Sipunculids, which have leathery bodies, one end of which can be drawn out into a long proboscis, a feature also of the beautifully coloured Nemertines, which have soft and very extensile bodies, which often break into pieces when handled. The bristle-worms are commonest of all, and include many of the kinds we have already mentioned as well as others only found in this region. The most remarkable of these is the peculiar tube-dwelling Chætopterus, which lives in sand or mud occupying a parchment-like tube. In the middle of its body are three broad segments which beat rhythmically—even when detached from the rest of the body—and maintain a steady current of water through the tube.

Commonest of all are crustaceans of all sizes. One of the barnacles, Scalpellum, attaches itself to hydroids and is remarkable in that the large specimens are all female, the males being minute creatures which live attached to the females. Various ghost-shrimps and many members of the prawn and lobster family are common on the bottom. Of the latter may be mentioned the Norway lobster (*Nephrops*), which lives on muddy bottoms (Plate 113), and the majestic rock lobster (*Palinurus*) with its handsome brown, sculptured shell but without the large claws of the common lobster (Plate 114). There are also squat-lobsters, such as the small Galathea and the larger Munida, which have long claws and broad, flattened bodies, the tail, normally bent under the body, being straightened out for use in swimming. Various kinds of hermit crabs scavenge over the sea bottom. Of the numerous crabs, there are the large red spiny spider crab (*Maia*), the largest and most heavily armoured of the spider crabs, and, in more northern waters, the somewhat similar northern stone crab (*Lithodes*), which is stone grey in colour, and innumerable smaller kinds, some of which live in sand like the angular crab

(*Gonoplax*), which has a reddish-brown rectangular shell and eyes on the ends of movable stalks.

A great host of molluscs find a home on the sea bottom, the most conspicuous being large snails such as the whelks, which include the common Buccinum, the smooth-shelled Fusus and Sipho, and Neptuna, with bold ridges running round its shell, the two latter being especially northern beasts. The shell of these, and similar, animals is frequently covered with a moss-like growth which on examination proves to be a very interesting hydroid called Hydractinia, which has three kinds of polyps, for feeding, reproduction and defence, respectively. Our largest sea slug, the Triton (*Tritonia*), is frequently found at these depths ; it is pale coloured of various shades and browses on Dead-men's-fingers ! The boat-shell (*Scaphander*) ploughs its way through sand in the search for the small bivalves on which it feeds. Another strange beast living in sand is the Elephant's Tooth, our sole representative of a small but distinct group of molluscs, which, as its name suggests, has a long tapering shell, open at both ends. The empty shells are frequently taken possession of by a small Sipunculoid worm (never by hermit crabs, which always live in spiral shells), which closes up the main opening except for a small hole through which it protrudes its long proboscis. The varieties of bivalves are legion, from the large, very thick-shelled *Cyprina islandica* of the North Sea to the many smaller kinds which are often almost incredibly abundant. Thus on the Dogger Bank one such named Spisula, occurs in patches often fifty miles by twenty and at a density of anything from one thousand to eight thousand to the square metre, while another, called Mactra, is found in patches of fifteen to twenty miles in diameter and up to seven hundred per square metre. Everywhere abundant are the many different kinds of Scallops, varying in size from the large

Pecten maximus, up to five inches across, to species with not more than a tenth of this diameter.

The octopus is an inhabitant of this region (and of shallower water in the more southern waters, being found on the shore in the Channel Islands). It prefers rocks, hiding in cracks and holes, for it can flatten its body so that it enters narrow slits in the rock, and darts out on fish and crustaceans as they swim by unsuspectingly. The common British species, found in numbers along the south coast, is the Lesser Octopus (*Eledone*) (Plate 27), which differs from the larger species (*Octopus vulgaris*) in its smaller size and the possession of a single, instead of a double, row of suckers on each of its eight arms. The latter is not common on British shores though it occasionally comes into the English Channel from further south during hot summers, doing great damage to the crab and lobster fisheries. In spite of its ungainly appearance, the octopus is capable of rapid and graceful swimming and possesses a larger brain and more highly-developed eyes than any of the other Invertebrate animals; indeed, in the complexity of the latter organs it is the equal of ourselves.

Amongst the animals we have not yet mentioned are various lesser known but interesting creatures. In some parts the sea bottom is covered with luxurious growths of the sea mats, the most conspicuous being the Ross (*Lepralia*), which forms a massive skeleton consisting of many delicate limy sheets, while two others, Cellaria and Flustra, are frequently taken in great quantities in the dredge. Sea squirts of various kinds are found but are not so abundant as on the shore or in the Littoral zone.

Deep-Sea Zone

The fauna of the Continental Slope—the Continental Deep-sea zone—is most easily studied in the Norwegian

Fjords, many of which descend abruptly from the shore down to depths of five hundred fathoms or more. Many of the animals taken in the dredge are of extraordinary interest and beauty, but we can here only refer to a few representative types. On rocky bottoms there are masses of the stony coral, Lophohelia, which forms branching colonies bearing delicate polyps like orange-flowers on a yellow bush, with it are often great tree-like growths of the giant gorgonid, Paragorgia, which is bright scarlet. Sea pens (Plate 73) are common on soft bottoms, red, yellow or brown in colour, and varying in length between a few inches and a yard or more. Below one hundred and fifty fathoms may be found the big bivalve, *Lima excavata*, often six inches long and four or five inches wide, which has bright orange tentacles and flesh, the latter being considered a great delicacy by the fishermen. In similar localities the dredge brings up numbers of lamp shells or Brachiopods, representatives of an extremely old, and probably dying, group of animals which have a bivalved shell enclosing the body and hardly to be distinguished by the casual observer from the bivalve molluscs. There are, however, many differences, the shell valves are unequal in size, have a different kind of hinge and the animal is attached to rocks by a small stalk which passes through a hole in the larger half of the shell. Starfish and brittlestars are exceptionally abundant, the latter including the fine specimens of Gorgonocephalus (Plate 28), the long arms of which divide and sub-divide to form a writhing mass of tentacles like the hair of the Medusa it has been named after. Large red and brown sea cucumbers are very common, and also deep-sea sponges some with root-like extensions for anchoring themselves in the mud, and others which grow on rock, one such, named Geodia, forming great rounded masses, often many feet across, dead white in colour and of

Pl. 26. *F* 70.

Sea Fan (*Gorgonia verrucosa*), ½. (p. 66).

Pl. 27. P. 71

Octopus *(Eledone moschites)*, $\times \frac{1}{2}$. (p. 69).

strange shapes like the whitened bones of some prehistoric monster !

Abyssal Zone

Owing to the remarkable conditions there prevailing, the inhabitants of the Abyssal zone are quite unlike those of the Continental Shelf, far fewer in numbers and quite different in appearance. The Continental Slope which connects these two regions is seldom traversed by animals passing from the one zone to the other for the conditions in the great depths are such that its inhabitants have to be very specially equipped for life and are unable to adapt themselves to existence in shallower water. Conditions are more uniform in the abyss than on any other part of the earth's surface. There is absolute darkness, an unchanging temperature only slightly above zero and an enormous pressure amounting, at depths of three thousand fathoms, to about three tons per square inch. There is no vegetation and no exposed rocks, everything being covered with a layer of soft ooze. The place of attached animals is taken by creatures with long stalks, which lift their bodies clear above the mud. Examples are provided by the sea lilies (Plate 25), closely related to the feather-stars of shallower water but with a long stalk in place of the short root-like outgrowths, and also by the sea pens, here at their most abundant, some alcyonarian corals, sponges, sea squirts and sea mats. Many of the crustaceans have long legs for lifting their bodies above the mud, and so have the sea spiders which may have limbs two feet long (Plate 25). There are relatively few animals with calcareous skeletons, molluscs, especially bivalves, being particularly rare, though some interesting examples of the latter which, unlike their shallow water relatives, have become carnivorous, are found in the greatest depths. The total darkness has resulted, para-

doxically, in some deep-sea animals losing their eyes completely, while others have developed especially large ones, sometimes on the ends of long stalks, like telescopes, perhaps capable of detecting any gleam of phosphorescent light.

Many deep-sea animals are of graceful and slender build, a result, probably, of the complete lack of movement, for there is no need for a strong skeleton and powerful muscles if water currents and tides are absent. Striped and spotted animals, so numerous in shallower water, are remarkable by their absence, practically all deep-water animals being of a uniform colour, usually white, grey, black or red ; blue and green animals are never found. Many of the fish have great jaws and powerful teeth by means of which they prey upon one another, other animals feed on the dead bodies which rain down from the surface miles above, while others again, such as the numerous many-coloured sea cucumbers, plough their way through the ooze, swallowing it as they go and extracting such nourishment as they are able.

Associations

In each of the areas we have considered, Littoral, Sublittoral, Continental Deep-sea, and Abyssal zones, we find definite associations of animals in different localities and on different types of bottom. Just as on the shore, the animals composing the associations are especially suited to the particular conditions and also probably assist one another, for life is a unity and its various constituents are dependent one upon another. Very little was known of these associations of bottom-living animals until recent years, when the Danish Biological Station commenced to study them, using for the purpose, not the dredge which gathers haphazard from the sea bottom, but the more exact grab which takes definite samples of the bottom (see page 263).

It might appear at first sight as though this knowledge was of quite secondary importance and not worth the very great labour its collection undoubtedly entails. But this is far from being the case. We have already referred to the unity of life, and here is an example ; the bottom animals, especially the shellfish and worms, form the most important part of the food of the bottom-living fish, such as the different flat-fish, the skates and the haddock, and it has been shown by the Danish investigators that the success or failure of the fisheries in any year is largely dependent upon the numbers of other members of the bottom fauna, especially shellfish, in that year. On the other hand the prevalence of starfish has just the opposite effect for these animals—from the fisherman's point of view—are pests, pure and simple, they are of no use to man while they destroy countless numbers of shellfish.

Adaptations

Different animals are adapted for life under different conditions, and the bottom-living aniamls possess many structures and peculiarities which fit them for life on the sea bottom. We have already spoken of the manner in which burrowing animals maintain connection with the surface, while in Chapter IX we shall see something of their devices for obtaining food. There is also the vital matter of reproduction. Very many of them produce eggs which hatch out into animals totally unlike their parents. Starfish and their relatives provide the most striking examples of this, but worms and crustaceans afford instances almost as striking (compare the adult crab in Plate 14 with the young of the same species shown in Plate 43). These "larvæ" do not stay at the bottom but rise towards the surface, where they are for a time part of the drifting life, described in Chapter V, and only settle down to the humdrum life of their parents

when they begin to assume the adult form. The young of animals which live in very deep water would have difficulty in rising several miles to the surface for a floating existence of perhaps only a few weeks or even days, and then dropping back that great distance, and as a result we find that the development of deep-sea animals is "direct," i.e., there is no strange "larval" stage, when the young are free in the sea, between the egg and the fixed adult, but the latter develops directly from the egg. The advantage of the former method in ensuring the wide distribution of the animal concerned will be obvious. The spawning habits of bottom animals are many and various, but, as with the shore animals, can be divided into three main types, where the reproductive products are shed indiscriminately, where protected spawn is laid, and where the developing young are carried about by the parent.

Bottom animals do not make long migrations like the fish. This is impossible in the case of the many attached or rooted animals while a large number of the others are too sluggish to move far. Octopuses certainly move from place to place causing, as we saw, great damage when they suddenly invade new areas, but this is probably the result of exceptional temperature conditions and not a seasonal occurrence. Crustaceans, at any rate the larger ones, are active beasts and can move about freely; many, like the edible crab, coming inshore in the summer and then retiring into deeper water in the winter. In the summer the shore waters are warmer than the deeper water, but in the winter the reverse is true. Another animal which can move about is the scallop, especially the smaller "queen" (*Pecten opercularis*) which, by the continuous flapping of its shell valves, is able to swim about, hinge side hindmost (a process which is reversed when the animal is alarmed)

(Fig. 11), a habit possessed only by a few other scallops and the delicate *Lima hians*. The queen lives in large "shoals" which are able to move freely about the sea bottom changing their feeding grounds from time to time. Indeed there is a constant movement on the sea bottom,

FIG. 11.—Diagram to illustrate swimming of scallop.

Left—Normal mode of swimming, upper arrow showing direction of movement. Lower arrows direction in which water is expelled.

Right—Movement when startled, hinge foremost, right arrow showing direction of movement, left arrow direction in which water is expelled (after Buddenbrock)

particular animals mysteriously disappearing from a given area and then as mysteriously reappearing, and we know nothing either of the cause or the extent of their movements.

CHAPTER IV

Swimming Animals

OVER the sea bottom lie the waters of the ocean extending for miles in all directions. Above the surface of the land the air is the medium through which birds and insects, and even man, can make their way with great speed. In the same way the sea water forms a medium through which certain animals can travel rapidly from place to place by swimming. Although many minute animals can swim (in the true meaning of the word), that is, make their way through the water, it is usually agreed that the real swimming animals of the sea are those only who can make headway with sufficient speed to move from place to place against any current they may meet. Those smaller creatures that can swim without sufficient strength to stem the currents, and are drifted to and fro by them, are usually classed under the heading of drifting life, and will be dealt with at length in the next chapter.

The true swimmers are to be found in only a few groups of the animal kingdom, and are the fishes, the whales and seals, and the squids or cuttlefish.

FISHES

Most sea fishes can be divided into two main groups, the cartilaginous fishes or Elasmobranchs, and the bony fishes or Teleosts. In the group of cartilaginous fishes are to be found all the shark family—dog-fish, tope, sharks, rays and skates. These are characterized by the fact that no

true bone is to be found in their skeletons, but that they consist of that curious transparent substance known as cartilage, which, for all its delicate appearance, is in reality very tough. In the bony fishes on the other hand, the skeletons are all made of true bone, which is hard and brittle. This is only a further stage in evolution, bone being actually cartilage within which strengthening deposits of lime have been added. The skeletons of very young animals consist of cartilage, and it is only as they grow that the lime is deposited to build up bone. This being the case it is not surprising to find that the cartilaginous fishes are more primitive than the bony fishes, and appeared first in the course of evolution. In the struggle for existence during the history of the world, however, the fishes with true bony skeletons have been by far the most adaptable and are now far more numerous both in kinds and in numbers than are the shark family.

But this is not the place to enter into a scientific discussion on the evolution of fishes or to describe in detail all the many different species of fishes that exist at the present day. It is rather the intention of these pages to show how some of the various fishes behave and live in nature and the part they play in the world under the sea.

Spawning Habits

In describing the life of any fish, it is reasonable to begin from the day of its birth. Most marine fishes, but not quite all, lay eggs; only a few are viviparous, that is, are born alive and do not hatch from an egg previously shed by the mother. Amongst these few are the viviparous blenny (*Zoarces*), one or two kinds of dog-fish and the saw-fish (*Pristis*).

But let us consider the majority, that is the egg-laying fishes. Some fish lay their eggs on the sea bottom attached

to stones, shells and weed. In these cases the eggs when first shed are covered all over, or in certain places, with a sticky secretion, which soon hardens and glues the egg fast to the stone or shell with which it may be in contact. This method is typical of many of those little fishes which are so common in the rock pools and the tidal zone. The blennies, the gobies and the suckers, all fasten their eggs in little clusters to the insides of empty shells, and under overhanging ledges or in crevices in the rocks.

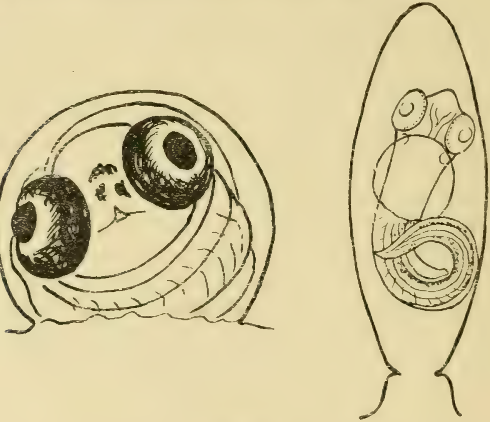
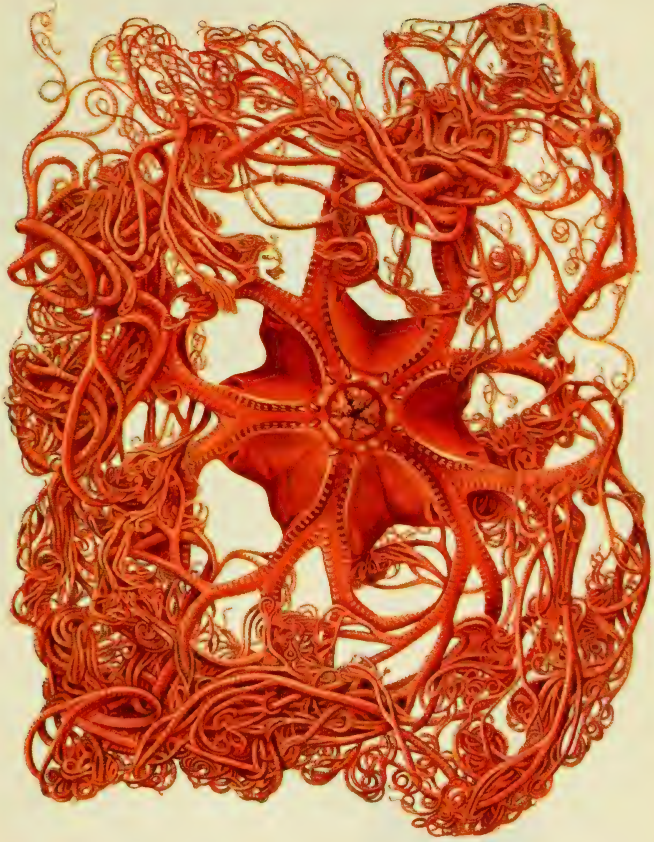


FIG. 12.
Egg of Blenny (x 25) Egg of Goby (x 20)

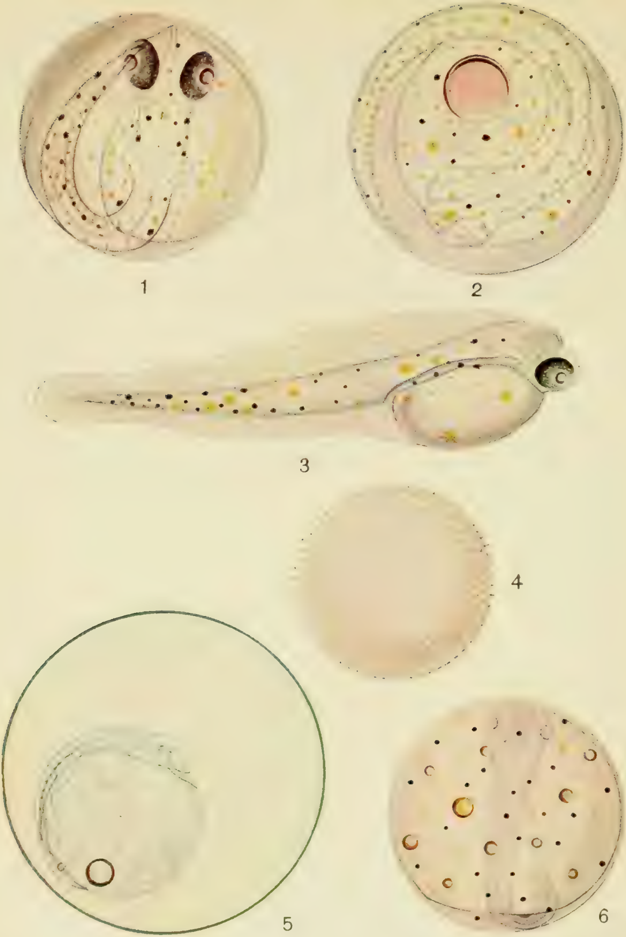
The eggs, which are comparatively few in number, vary considerably in shape. Those, for instance, of the common blenny are rounded or spherical, with a little disc-shaped base that cements them to the rock, while those of the gobies are elongated and flattened (Fig. 12).

It is quite a common occurrence for these kinds of fishes to guard their eggs. Not infrequently a blenny (*Blennius*



Pl. 28. *F* 78

Gorgonocephalus Agassizi. × ½. (p. 70).



Pl. 29. DEL. H.O.B. *F* 79.

Fish Eggs and Larva, 25. (pp. 80, 131).

1. **Whiting** *(Gadus merlangus).*
2. Gurnard *(Trigla gurnardus).*
3. Whiting *(Gadus merlangus).*
4. **Dragonet** *(Callionymus lyra).*
5. Pilchard *(Sardina pilchardus).*
6. Weever *(Tr[illegible]us vipera).*

ocellaris) may lay its eggs inside a bottle, and if this bottle is dredged up in a net it is quite likely that the parent will be found inside keeping watch over them. They have even been found inside an ox-bone.

The gunnel or butterfish (*Centronotus*) guards its eggs by coiling itself completely round them, as can be seen in Plate 32; the male stickleback and several species of wrasse build nests of weed within which the eggs are deposited. In the case of the pipe-fishes, which live amongst the sea grass, the males carry the eggs in a pouch under their tails.

Almost all of our food fishes and many others, however, show no such parental solicitude for their offspring's welfare. They merely cast their eggs forth freely into the water, and these eggs are not heavy and sticky as those mentioned above, but are so nearly of the same weight as sea water that they drift about in the water layers at all depths between the surface and the bottom. Here they are at the mercy of tide and currents and are carried many miles from the region where their parents spawned. The dangers are many; they are not in sheltered crannies with parents to guard them; there are enemies all around to devour them; if their own parents happen to meet them again they will eat them with the greatest relish. What then is the provision for their safety? There is a well-known proverb, "there is safety in numbers," and perhaps nowhere does this hold better than in the case of these care-free fish. We remarked above that those fishes who fixed their eggs to the rocks laid comparatively few; by this is meant never more than a thousand and probably considerably less. But what is this to the five million eggs a cod will lay, or the eight million laid by a turbot? And yet such are the dangers to be faced during the life of a fish that it is doubtful whether, at most, as many as ten out of these millions will survive to maturity.

These drifting eggs are to the naked eye like little glass-clear balls, varying in size from that of a small pin's head to about that of a radish seed. When first cast out into the water the eggs of many kinds of fishes are indistinguishable save by slight differences in size. But after a few days the young fish begins to form within the egg and there appear upon it flecks of colour, black, yellow or red, generally so disposed on the body of the fish as to make the different species quite distinguishable (Plate 29). There are, in addition, in many eggs, globules of oil which either by their size, number, or colour, make it at once apparent to which species they belong. Thus to the specialist the identification of fishes' eggs becomes no harder than does that of the birds' eggs on land, the only difference being that it generally has to be carried out under the microscope.

The eggs of the Angler Fish (*Lophius piscatorius*) present a striking contrast to these single drifting eggs. In this case the eggs are kept together in a large ribbon of jelly, which may float at the water surface. Egg masses of the Angler Fish have been reported several square feet in extent, flat expanses of jelly carrying millions of eggs.

Practically the only one of our food fishes which does not lay drifting eggs is the herring. The herring's eggs are deposited on the sea floor, in certain localities only, on stony ground (Plate 112). The eggs are sticky and cling together in clumps in the crevices between the stones among which they fall. They are much enjoyed by other fish as food, especially by the haddock (*Gadus æglefinus*); indeed, some of the spawning grounds of the herring have been located by the fishermen owing to the presence in their trawl catches of what they call "spawny haddock," that is, haddock whose stomachs are packed full with the herring's eggs.

Many skates and dog-fishes have curious eggs, which are

very familiar to those accustomed to rambling along our beaches. They are the so-called " mermaids' purses," little horny capsules with spines or tendrils at the four corners. The smaller, narrower type, with long curling tendrils at its corners, is that of the dog-fish (*Scyllium*), while the large, broad ones with the four spines, belong to the skates (Plate 31). The dog-fish eggs are attached to sea weeds by the parents, who wind the tendrils securely round the stem of the weeds; these eggs are occasionally to be found on weeds at low tide with the yolk and small developing fish inside, because the " mermaid's purse " is of course merely the case in which the egg lies. The skate's eggs, on the other hand, are deposited in deeper water, where they are buried in the sand with the two spines projecting above the surface, and through these a current of water is drawn into the case by the developing fish for breathing purposes. These eggs of the dog-fishes and skates take many months to hatch, although most other fishes hatch out within about a fortnight after the eggs are laid.

One of the most surprising cases of spawning instinct is exhibited by a little fish that abounds on the shores of California. This fish, the Grunion (*Leuresthes tenuis*), belonging to the Atherine family, deposits its eggs in the sand at the high-tide mark along the sandy beaches. This it does one to three days after the highest spring tide, burying the eggs two or three inches beneath the surface of the sand. Here the eggs remain and develop, until in a fortnight's time, when the high tides once more cover them, they are ready to hatch. Now notice the providence of nature. If those eggs had not been laid just after the highest spring tide there is quite a possibility that the next high spring tide a fortnight later, might not have been quite so high, thus preventing the eggs from being reached by the water; and in this case, being ready to hatch, they could

not survive another fortnight. Also, by being laid after, instead of before, the highest tide, they would be unlikely to be washed out of the sand before they had fully developed, since each successive high tide would be slightly lower until the spring tides started once more.

Early Life

In most cases when first the baby fish hatch they are extremely small. A young whiting (*Gadus merlangus*), for instance, which is typical of many marine fishes, is only about a quarter of an inch in length. It carries on its under surface an oval sac of yolk on which it is nourished for the first few days of its free existence (Plate 29). When this supply is exhausted the young fish starts to feed. At this stage in its life the fish is drifting freely in the water layers above the bottom, and because of its small size and feebleness it can make no headway against the currents, but is carried along by them. All around is a community of other drifting animals and plants, and on these the little whiting makes its meals. After drifting thus for a fortnight or longer the fish begins to assume its adult character and appears as a true miniature of its parents. It is then about an inch in length and can swim with considerable agility, and seeks out new grounds in its search for food ; some kinds of fish at this stage take to the sandy bottoms, while others seek the rocky coves and bays along the coasts. In the case of the whiting, however, a very interesting stage in its life-history has yet to be passed through. The little fish seeks out those big blue jellyfish, the Cyanea (Plate 30), which abound at the same time of the year. These beautiful animals vary in colour from a deep brown red to the most heavenly ultramarine blue. They can be found of all sizes, from that of a small mushroom upwards to as much as a foot in diameter, and they have even been recorded in the

cold northern waters to reach the immense size of seven and a half feet across, with tentacles 120 feet in length. These tentacles are armed with batteries of stinging cells. Under the shelter of these jellyfish the small whiting find a temporary home. On a calm day it is at times possible to see one of these jellyfish floating near the surface of the water, and all around within a radius of a few feet can be seen numbers of these little whiting darting about picking up their food. A sudden splash with the oar will drive them all beneath their curious shelter where they rest secure, trusting in the stinging powers of their host as a protection against their enemies. And the amazing thing is that the jellyfish allows it and does not attempt to capture them. In European waters the baby horse-mackerel (*Caranx trachurus*) also seek this floating shelter, while in American waters young butterfish (*Poronotus triacanthus*) do likewise, as well as young haddock and cod from both sides of the Atlantic.

All our flat-fishes, such as plaice and soles, spend the first days of their lives drifting freely through the water. But at this period they are rather unlike their parents. The full-grown fishes, as we all know, have both eyes on the same side of the head; but not so the very young fishes, which are quite symmetrical, with one eye correctly placed on each side of the head. After two or three weeks, however, the eye on one side begins to move and slowly travels over the top of the head until it reaches the other side. At this stage the fish turns over on its side and seeks the bottom where it lies, with eyes both pointing upwards. This shows that many of the flat-fishes are flattened sideways, and are, indeed, living on the bottom on their sides. Such fishes are the plaice, the sole, the brill, the turbot and many others. Some fishes, however, such as the skate and the Angler Fish, may be flattened from above downwards,

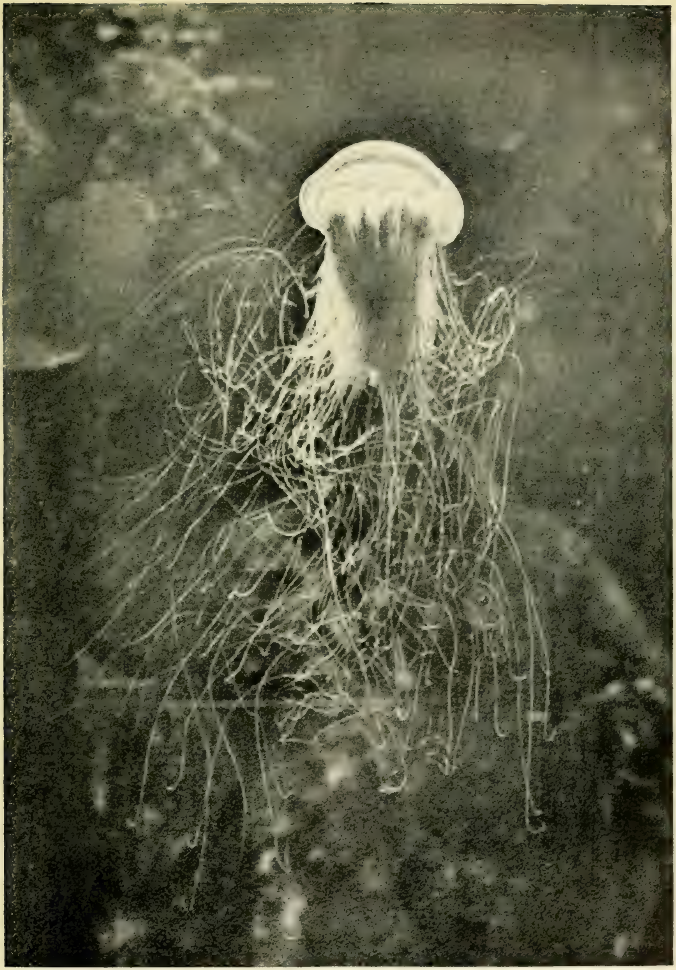
in which case they swim over the bottom truly on their stomachs.

The young stages of many fish are totally unlike the adults. The Angler Fish, for instance, so shapeless and cumbersome when grown up, is a most beautiful object soon after hatching (Plate 37). Its fins are drawn out into filaments of fairy-like delicacy. Like other young fish, the Angler spends its early days drifting in the water layers above the bottom, and the long-drawn-out filaments of the fins help to keep it suspended in the water.

Migrations

It is obvious that, if, for several weeks in the early stages of their lives, most fishes are going to drift freely about at the mercy of tide and current, they will be carried far from where their parents shed the eggs. The greatest importance therefore attaches to the position of the spawning ground, from which after a definite time the young fishes must have been carried to suitable grounds for feeding and growing. For this reason many adult fishes undergo spawning migrations, that is, they move off all together to a chosen locality to shed their eggs. The plaice, for instance, in the southern North Sea move further south (Fig. 61, p. 323), so that their eggs and young are drifted by the prevalent currents on to the so-called " nurseries " in the shallow, sandy bottomed regions along the coasts of Holland. The herring, too, move in from deeper water to deposit their eggs on the bottom in certain regions, and it is then that the fishermen set to work to catch them in the drift nets.

But most surprising of all spawning migrations is that of the common fresh-water eel. For years men in all countries of Europe have wondered how it is that the eels in our streams thrive and multiply, and yet nobody had ever seen



Pl. 30. *G* 84.

A Jelly fish *(Cyanea capillata)*, $\times\frac{1}{4}$. (p. 82).

Pl. 31. DEL. W.R. *G* 85.

1. **Egg-case of Dog-fish** *(Scyllium canicula).*
2. **Egg-case of Skate** *(Raia naevus).*

(pp. 81, 82). Natural size.

their eggs or their very tiny young. Izaak Walton in his *Compleat Angler* says: " Some say that they breed, as worms do of mud; as rats and mice, and many other living creatures are bred in Egypt, by the sun's heat when it shines upon the overflowing of the river Nilus; or out of the putrefaction of the earth, and divers other ways . . ." " and others say, that as pearls are made of glutinous dewdrops, which are condensed by the sun's heat in those countries, so eels are bred of a particular dew, falling in the months of May or June on the banks of some particular ponds or rivers . . . which in a few days are, by the sun's heat, turned into eels."

But just as we know that pearls are not made from dew-drops, so are we now certain that eels do not spring from mud, or putrefaction, or drops of dew. For in the year 1922 a great Danish oceanographer, Dr. J. Schmidt, found the true spawning place of the eel and cleared up the mystery once and for all. He disclosed the amazing fact that when the eels in our rivers become mature they set off on one of the longest journeys as yet known to be undertaken by any fish.

When the common fresh-water eel of our rivers has reached a length of about a foot, it changes its appearance and puts on what is known as its " spawning livery." Instead of its usual yellow colour it becomes quite silvery in appearance and hence at this stage is known as the " silver eel." In this condition the eels work their way down to the mouths of the rivers. In the late summer and autumn this migration takes place and the eels push on out of the estuaries and into the open sea. Then starts the long, long journey out into the deep water and so into the Atlantic Ocean. Of the speed at which the silver eels go on their journey we know little. Once into the deep water they become lost to our observation. In the Baltic

they have been captured and marked. Their recapture on their way to the North Sea shows that they had travelled at the rate of about nine miles a day for some three months, but they were only a very short way on their total journey, for the next we know of them they must have arrived in the deep central part of the North Atlantic, known as the Sargasso Sea (a distance of some two to three thousand miles), although none of the spawning eels have themselves been seen there. There is, however, irrefutable evidence that they must have been to those regions, because at the end of winter and during spring the baby eels are there. The young eels are very unlike their parents ; in fact so unlike that the first time one was seen it was considered to be a new species of fish and given the name of "Leptocephalus." They vary from a quarter of an inch to three inches in length according to their age. They are flattened sideways so as to resemble a leaf, and are quite transparent (Plate 35). These baby eels now start on the return journey and we can in this case get some idea of the rate they travel, for Prof. Schmidt has, by measuring very large numbers, shown that they take three years to reach the European shores once more. During the long journey across the Atlantic they grow, and it is by their growth that their birthplace has been located ; catches made between our shores and the central Atlantic exhibit these eel larvæ in ever decreasing size (Fig. 13). Near the coasts they are about three inches long, but down in the locality of their birth they are only a quarter of an inch in length, and indeed, in this region, eggs have been taken that are without a doubt those of the parent eels themselves. The eggs are about the size of a pea, quite transparent, and drift in the water layers at depths of about a hundred fathoms, just like many of the other fishes' eggs mentioned earlier in this chapter.

When the eel larvæ have reached their destination on the

coasts of Europe, a very remarkable change comes over them. From their leaf-like shape they gradually assume a true eel-like appearance, becoming narrower, rounder, and at the same time slightly shorter in length. After this change has taken place they are the typical little eels, known as " elvers," that ascend some of our rivers in such countless numbers. Here they remain in fresh water, feeding and growing. After a course of time, that may vary

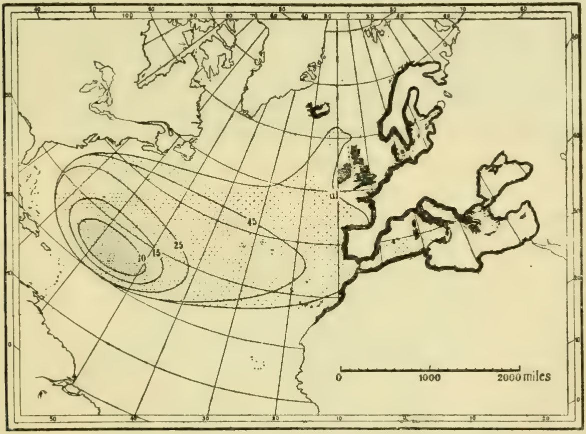


FIG 13.—Distribution of larvae (dotted area) and of adults (black stripes along coasts where species occurs) of the European Eel. The contours show the limits of occurrence of the different sizes, i.e. larvae less than ten millimetres long have only been found inside the ten millimetre curve. u.l. is the limit of occurrence of unmetamorphosed larvae (after Schmidt).

from five to twenty years, the eel puts on its silver spawning dress and once more sets out on the return journey to that deep part of the Atlantic where it spawns and probably dies.

There is in America an eel which is very similar in appearance to the common European fresh-water eel, only differing in certain minute anatomical details. This eel undergoes

a similar life-history to that just described for our eel, with the only difference that the spawning ground is slightly to the west of that of the European eel, and the leaf-shaped larvæ take only one, instead of three years before they are ready to ascend the American streams as typical elvers (Plate 35).

This difference in the life-histories of the European and American eels is of great interest in showing the speeding up or slowing down of development to suit the environment. If the larvæ of the European eel took only one year to reach metamorphosis they would still be far from their destination on the European coasts, when they had assumed the shape at which they normally ascend the rivers; while the American eels by a reduction of the period of larval existence are ready for metamorphosis by the time they have arrived at the American coasts.

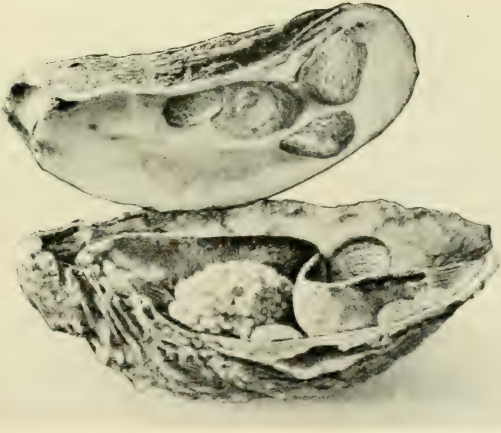
A somewhat similar, but reversed, life-history is that of the Atlantic salmon (*Salmo salar*). In the case of this fish, while the adults undergo most of their growth in the sea, they move up into the rivers to lay their eggs. The young live for two or three years in the fresh water before migrating down to the open sea to feed on the large food supplies available there and to make that very great growth that distinguishes them from their relatives the trout, who spend all their lives in the rivers.

Distribution

It can be seen that, because of the large journeys carried out by many fishes, the area of their distribution must vary at different times of the year and be rather widespread. Nevertheless there is noticeable, in the seas of the world, quite a definite zoning of the distribution of different species of fishes. There are, of course, differences in distribution to be found between such fishes as live always in the tidal

Above: "Pen" of Squid *(Loligo Forbesi)*

Below: "Bone" of Cuttlefish *(Sepia officinalis)*, ×⅓. (p. 106).



By permission of F. W. Gudger.

Pl. 32. *G* 88.

Gunnel or Butterfish *(Centronotus gunnellus)* **guarding its eggs in an empty oyster shell,** ×⅔. (pp. 36, 79).

Pl. 33. The Rat-tail (*Macrurus aequalis*), $\times \frac{2}{3}$. (p. 91). G 89.

zones or in the vicinity of rocky coasts, as opposed to those of more open water. Such differences can be noticed in comparatively small areas; but there are, as well, differences to be found over very large regions. Everyone knows that if he visits tropical latitudes he will see fishes that he never sees in more northern waters. A visitor to such widely separated fish-markets as those of Grimsby in England, Trieste in Italy, and Colombo in Ceylon, will at once be convinced of this. Each market will display its own characteristic fish, and it is doubtful whether any fish would be found common to all three markets. Such localization of faunas is easily understandable on land, where such barriers as deserts, high mountain ranges or large areas of water, limit the different animals to their own special regions. But in the sea, with all the oceans of the world connected, there are no such purely mechanical barriers present to limit the dispersal of the different kinds of fish and prevent them from presenting a perfectly uniform distribution from ocean to ocean and sea to sea. How is it then that one finds nevertheless that certain widely separated areas each possess their own characteristic population of fishes? It is evident that there must be some barrier, and a general exploration of the chemical and physical properties of sea water has shown that in all probability the chief factor in the distribution of the fishes is the temperature of the water itself.

It is generally to be noticed that in our northern waters, wherever the temperature of the water is less than ten degrees Centigrade, our typical northern fishes will be found, cod, halibut, haddock, herring, and many others. On our south-western coasts, those of Devon and Cornwall, we find that we are on the southern limit of the distribution of these northern fishes; and, at the same time, here occur the northern limits of certain southern warm-water loving

species. It is, so to speak, a meeting ground of the two great areas and certain fishes common to both occur. Besides the herring and the cod, both northern representatives, we have, for instance, the pilchard, and occasionally the red-mullet and the anchovy, fishes which are typical of the warm waters of the Mediterranean and Atlantic.

Within the large areas, also, it is to be noticed that there are further sub-divisions ; certain fishes which live in the very cold part of the Norwegian Sea, and in the Arctic waters, are quite characteristic of those regions.

In the tropics, again, the fish population is quite characteristic, and here are to be found many of the most brilliantly coloured fishes in the world.

In the geographical distribution of fishes, apart from these differences caused by temperature, there are also differences that are occasioned by the depth of the water. There are shallow-water fishes, deep-water fishes, and abyssal fishes, that is, fishes who live on the very flat plains in the deepest parts of the oceans known as the abyss.

It is natural that those fishes which will be limited to certain areas by depth boundaries are those that live most of their time swimming on, or close to, the sea bottom itself. Fishes such as herring and mackerel (so-called pelagic fishes), can have a much wider area over which to roam, because, swimming as they always do in the upper water layers, they can keep to the depths they most prefer, irrespective of at what depth the actual bottom of the sea may be.

As examples of fish whose distribution is limited by depth, we can name the plaice, which lives in the comparatively shallow flat areas such as the North Sea ; the hake, that roams along the deep-water shelf from one to five hundred fathoms, that constitutes the continental slope ; and that curious fish of the cod family known as the

Macrurus or rat-tail, who spends the greater part of its life in the cold dark depths over the abyssal plain (Plate 33).

These remarks on the distribution of fishes will help to explain also the distribution of some of our large sea fisheries. Certain fish, such as the mackerel (*Scomber scomber*), which prefer warm water, will be found around the north coast of Scotland and also in the North Sea. This, at first sight, appears rather contradictory, but the explanation is simple when we realize that there lies the course of the Gulf Stream, and it is to the warm waters of this oceanic current that the mackerel are keeping.

It is evident that all the fishes that live most of the time on the bottom will be limited by the depth barriers to coastal waters or the regions of comparatively shallow banks. There are however many fishes practically unknown to most people that may be termed oceanic. These fishes roam about all through the water layers out in the open oceans. They are mostly very small, the largest being a few inches in length. Many of them are very bizarre (Plate 34) in appearance and possess most interesting organs for the emission of phosphorescent light.

The distribution of these small oceanic fishes is also of great interest. They, like most other fishes, are apparently limited in their geographical distribution by those unseen temperature barriers. At the same time just as the bottom fishes appear to be restricted to areas within certain depths, so in the open waters of the ocean these fishes are to be found living, each species inside a definite limited range of depth above the ocean floor. There will be, for instance, those that occur mostly between the surface and one hundred fathoms; others, again, will never be met with in these water layers, but are only found below perhaps two hundred fathoms; and yet others may only be captured at very great depths, such as a thousand fathoms.

Shape

To the average person the word fish summons up in the imagination a silvery, wriggling, slippery animal of a certain definite torpedo shape.

This characteristic spindle or torpedo shape is admirably suited to the habits of most fishes. If we take, for example, a fish like the mackerel, we realize that not only is it beautiful and elegant, but that it is efficient; the fish is made to swim and nature has made no mistake. Just as man has learnt many lessons from the forms of birds to aid him in the designing of the most efficient aeroplanes, so can much be learned from the mackerel about the best shapes for rapid motion through the water. Its shape is "stream-lined"; that is, it is adapted so that in its progression through the water the least possible friction is set up and it can cleave its way without hindrance. If a square block of wood is placed in a flowing stream there will be considerable resistance on the front surface and at the same time many eddies will be created just behind it, which act as a suction and impede its passage through the water (Fig. 14). If now the front surface be rounded off the water becomes parted with a minimum of resistance; the water can now be seen to flow round the block in two streams which meet again some little way behind. Between the back surface of the block, the two surfaces of the divided stream, and

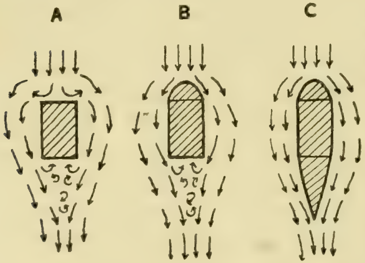
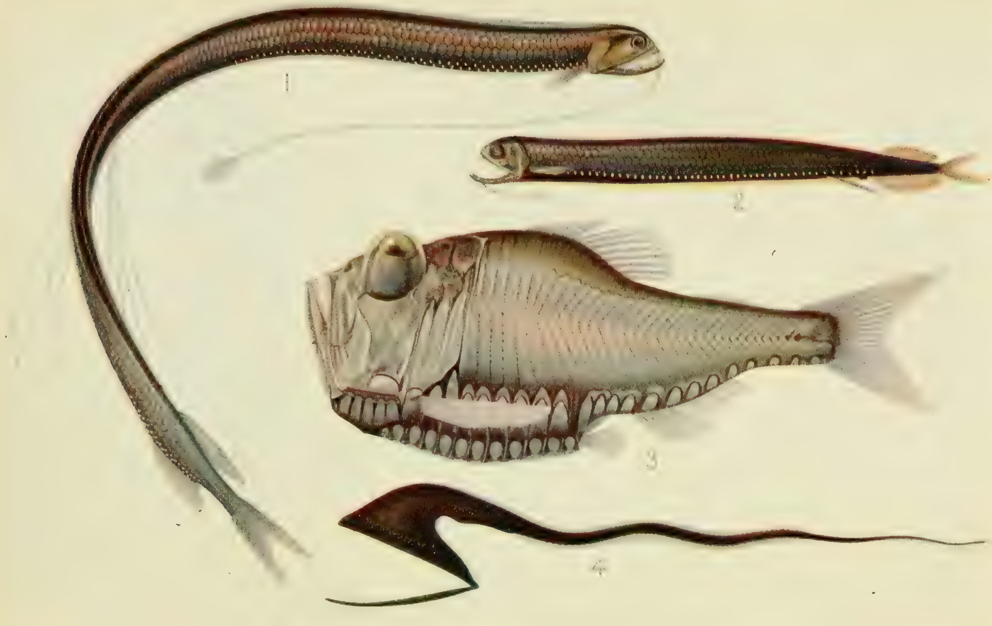


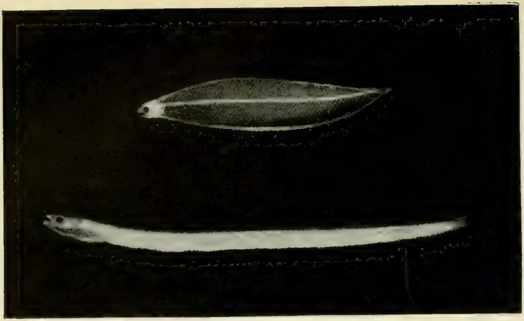
Fig. 14.—A, B, and C, are diagrams showing the successive building up of an oblong block into a stream-line shape to reduce resistance caused by eddies.



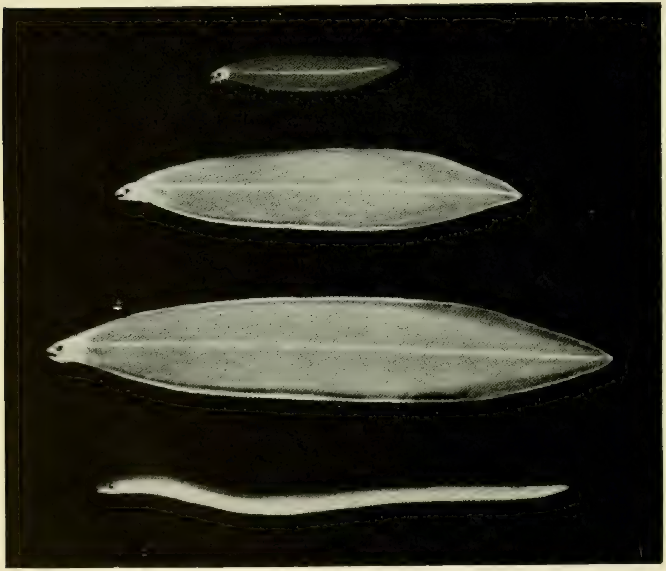
Pl. 34. *G* 92.

Deep-Sea Fish. (p. 91).

1. *Macrostomias longibarbatus*, $\times\frac{2}{3}$.
2. *Stomias valdiviae*, $\times\frac{3}{4}$.
3. *Argyropelacus affinis*, $\times 1\frac{1}{2}$.
4. *Macropharynx longicaudatus*, $\times\frac{1}{2}$.



Leptocephalus Larva and Elver of American Eel. Natural size. (pp. 86, 88).



Pl. 35. *G* 93.

Leptocephalus Larvae (1, 2 and 3 years old) and Elver of European Eel.
Natural size. (pp. 86, 88).

the point at which they meet, is a spindle shaped mass of water full of eddies. If the block be built up behind with wood of such a shape as just to fill this eddying area, then it will be found that the shape produced sets up the least possible resistance in its passage through the water. Its form is exactly the same as the outline traced by the water flowing round an object and hence the term "stream-line." It is just this shape that is typical of most fishes.

At the same time it can be shown that for different speeds slight variations are required in this outline in order to obtain the greatest efficiency. This probably accounts for the obvious differences in outline between slow-swimming fishes, such as the cod, and rapid swimmers such as the mackerel. A close examination of the mackerel shows that besides having this definite shape designed for high speed, there is a smoothing off of all excrescences that may set up resistance. The bones around the mouth and jaws, that in many slow-moving fish are somewhat projecting, are here inset absolutely flush with the smooth outline of the fish.

Very different in appearance are the fishes that live a great part of their time actually on the sea bottom. Many of them are quite flattened, so that they have a very large surface on which to lie, and their fins are so arranged that by a slight flapping they can throw up sand and pebbles, which settle down on the broad surface of the fish's back and eventually completely bury it from view. The common sole and the plaice are typical examples of flat fishes. They are remarkable in that in reality they are lying on their sides. As has been mentioned above, in their very youngest stages they are quite normally symmetrical like any other fishes, but at a certain stage, when they are between half and three-quarters of an inch in length, a

curious twisting takes place in their head region and the eye from one side travels round so that eventually both eyes come to lie on the same side of the head. The fish then turns over and settles on the bottom on its eyeless side. In some species it is the left eye which changes its position and in others the right eye, and it is rather unusual to find a fish with both its eyes on the opposite side to that typical for the species.

Other fishes, however, are flattened quite normally. The skates for instance are flat from above downwards and the eyes keep their same relative position throughout life.

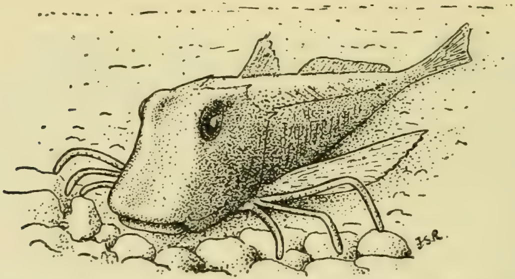


FIG. 15.—Gurnard, showing the separated fin-rays of the pectoral fin,

The gurnards are literally able to walk over the bottom. Just in front of the big fan-shaped pectoral fin on each side are three curved rigid spines, and if the fish be watched in an aquarium it will be seen that when moving over the bottom it is actually walking on the spines. The spines really belong to the fin ; they are fin-rays which in the course of time have broken away from the actual fin itself and evolved into these curious legs, which probably have a tactile purpose. (Fig. 15).

Another way in which fins have been modified, is to form

suckers by means of which a fish can hold on to a solid object. The common sucker (*Lepadogaster*) found in our rock-pools has a suctorial disc formed by a pair of fins on its under surface. In this case the resemblance of the sucking organ to the original fins can still be seen. But any fin-like appearance is completely lost in the case of the sucking disc of the Remora. This fish bears upon its head an object that looks more like the rubber sole of a sand-shoe than anything else. It is a very powerful sucker and with it the Remora fastens itself to the bodies of sharks and so gets rapidly transported from place to place and incidentally is able to pick up any remnants of food that the greedy host may drop. That this sucking disc is really a transformed back-fin has been discovered by an examination of the very early stages of the fish ; when it is only about half an inch long it possesses a normal back-fin like any other fish, but as it grows this fin gradually moves forward until it comes to lie on top of the fish's head, and in the meantime its structure is altering to that curious ridged form which acts as such an efficient sucker. The sucking action of this disc has been disputed, and it is thought by some that the clinging effect is brought about chiefly by friction.

The habit of the sucking-fish of fastening on to other fish has been taken advantage of by man, who actually makes use of the Remora to catch other fish. The method is practised by natives of such widely separated districts as the Caribbean Sea, Chinese waters and the Torres Straits. Although being used for catching certain fish such as sharks they are chiefly used for capturing turtles. The sucking-fish has a thin line attached to its tail. On sighting a turtle the natives row up to within fairly easy reach of it and then throw the Remora towards it. The fish immediately swims to the turtle and attaches itself to its

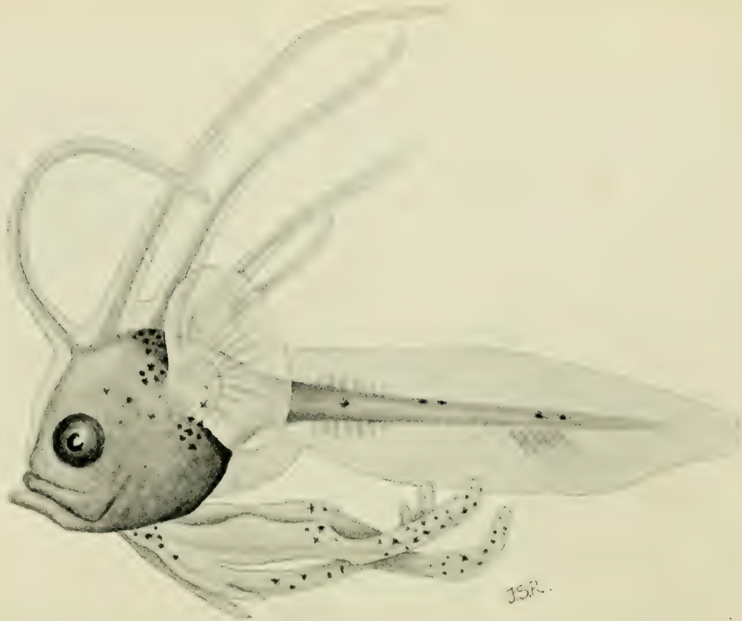
under surface. By pulling on the rope, the boat and turtle can then be brought close together and the turtle captured. At times, however, the turtle dives, and the Remora does not stick fast enough to allow sufficient strain to be put on to the rope to lift the turtle which clings hard to the bottom. Under such circumstances the native locates the exact position of the turtle by means of the string and then dives down himself and secures it with a rope. The practice has been studied in the region of the Torres Straits very thoroughly by Prof. A. C. Haddon, who says: "The sucker-fish is not used to haul in the large green turtles; I was repeatedly assured that it would pull off, as the turtle was too heavy; but small ones were caught in this manner." He goes into full details of the attachment of the leash to the fish and says, "I was informed that in leashing a sucker-fish, a hole is made at the base of the tail-fin by means of a turtle-bone and one end of a very long piece of string inserted through the hole and made fast to the tail, the other end being permanently retained. A short piece of string is passed through the mouth and out at the gills, thus securing the head end. By means of these two strings the fish is retained, while slung over the sides of the canoe, in the water (Fig. 16). The short piece is pulled out of the mouth of the fish when the turtle is sighted and the *gapu* is free to attach itself to the turtle." And after this, according to Prof. Haddon, the sucker-fish is eaten at the end of the day!

A very curious modification of a fin-ray is to be found in the common Angler Fish or Fishing Frog (*Lophius piscatorius*). In this case the front ray of the back fin is very elongated and bears at its tip a little tuft of filaments. The fish is truly named an Angler Fish for by means of this fin-ray it angles for its prey, which is lured on by the worm-like waving filaments. Even more curious are the near relatives

Pl. 30. G 96.

Deep-Sea Anglers. (p. 97).

1. *Ceratias Couesi*, $\times \frac{3}{5}$. 2. *Melanocetus Johnsoni*, $\times 1$. 3. *Melanocetus Kochi*, $\times 1$.



Pl. 37.

Young of Angler (*Lophius piscatorius*), ×8. **(p. 84).**

DEL. F.S.R. G 97.

of this fish which inhabit the dimly-lit layers of the ocean from 200 to 1,000 fathoms deep, the deep-sea anglers. In many of these the little lure at the end of the rod is phosphorescent and lures the unwary to their death, as did the wreckers on our coasts in days gone by (Plate 36). We can well imagine that, owing to the tremendous area over which these deep-sea anglers can roam in the open ocean, the chances of a male and female meeting are rather

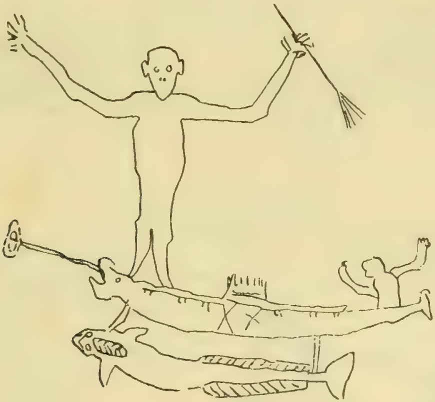
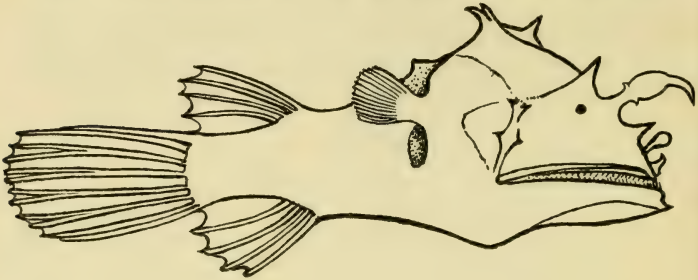


FIG. 16.—Native drawing of a sucking fish, or Remora, attached to a canoe (after Haddon).

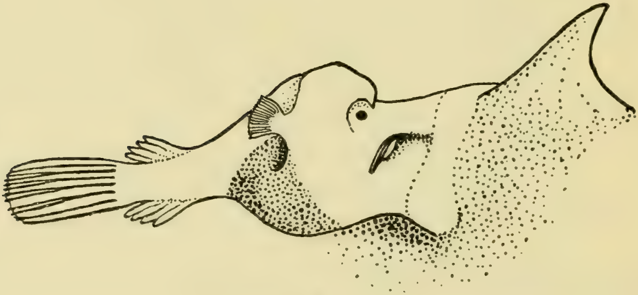
small. To overcome this there is a most remarkable provision. Females have been found carrying fused to their bodies tiny dwarfed husbands. It seems probable that while the males are still fairly numerous soon after they are born, before they have had time to be thinned out by their enemies, they fasten on to the first lady they can find, and there they stay for the rest of their lives. They become completely fused to their partners and lose all their

individuality, becoming merely appendages on their wives! (Fig. 17).

In the Flying Fish, *Exocœtus*, it is the pectoral fins that have become modified to offer an enormously large surface



A



B

FIG. 17.
A. Female deep-sea Angler (*Photocorynus spiniceps*) with dwarf male * attached to head (x 1 ⅜). B. Enlarged drawing of male showing attachment (x 6).

to the air, and so act as gliders when the fish leaps out of the water (Plate 38). Mr. E. H. Hankin says, " When starting a flight *Exocœtus* does not jump out clear of the water as a

rule. It only emerges by a jump so far that the front wings are clear of the water and at once expanded. The tail is then wagged vigorously to and fro, and thus, by sculling action (for which the enlargement of the lower lobe is helpful), increases the speed till suddenly the fish is drawn up into the air and remains in gliding flight with its wings at rest and sometimes, for a distance of several hundred

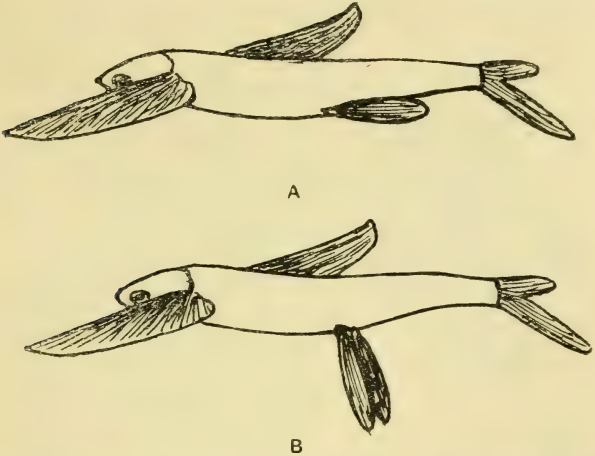


FIG. 18.—Showing position of fins of Flying Fish. A. When in full flight and B. before reentering the water, the pelvic fins being depressed to reduce the speed of flight (after Hankin).

metres, preserves a uniform height above the water. Occasionally, especially in cooler weather, slight fluttering of the wings does occur at starting, but the wings are nearly always at rest during the remainder of the flight" (Fig. 18). The flight is only a few inches above the water surface.

In the sea horse the fins are often reduced to mere vestiges or are absent altogether. The fish is covered with a hard,

jointed armour, and has a prehensile tail. There is a near relative of this fish which lives in Australian waters (*Phyllopteryx eques*) that is a piece of living camouflage (Fig. 19). All the knobs and spines on its body are prolonged into leaf-like filaments, which give the fish exactly the appearance of the brown sea weeds amongst which it lives.

The Torpedo, or Electric Ray, a member of the skate family, is remarkable for possessing on either side of its head two organs capable of generating quite powerful electric discharges. The electric organs are composed of muscular tissue in the form of innumerable small cells vertically arranged, the top surface of the organ being electropositive, and the bottom electronegative. A large fish of this species can give a shock sufficient to paralyse temporarily the arms of a strong man. At least one species occurs at times on the British coasts, but the majority live in warmer seas.

FIG. 19.—*Phyllopteryx eques*, a sea-horse (x ⅝).

WHALES

Whales are not fishes. They belong to the mammals, that large group of the animal kingdom the great majority of which live on dry land. Whales are in fact four-footed animals that, in the long course of evolution, have taken to the water for their permanent abode. Their external structure has, however, become so changed that they are almost fish-like in appearance, having the typical spindle shape

so characteristic of fast-swimming fish. They possess two large flippers where their front legs or arms should be. Many of them carry a vertical fin on their back and their tails are developed into powerful flukes; but unlike those of fish, these tails are flattened horizontally instead of vertically, probably to aid in the continual journeyings to the surface to breathe. An examination of the skeleton reveals the fact that the front flippers are undoubtedly the same as a true leg, for buried in the flesh are typical leg bones ending in numbers of small bones similar to those of our hands or feet (Figs. 20 and 21). But all these bones are completely buried and there is no external division of the flipper into arm, hand, and fingers. Although, externally, there is no sign of any hind limbs, yet in some species of

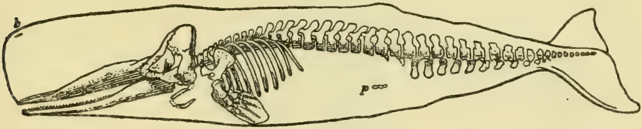


FIG. 20.—Outline and skeleton of Sperm whale or Cachalot (*Physeter macrocephalus*), *b*, blow hole; *p*, rudimentary pelvis.

whales, buried in the body in just the region where the hind legs should be, are to be found small remnants of bones much reduced in size and serving no purpose—the last vestiges of the back legs of the land mammal from which through countless ages the whales have been evolved.

Hair is one of the chief characteristics of mammals. It is essential for helping it to keep the warm blood that flows through their veins at the correct temperature. Yet a whale is practically hairless save for a few fine bristles in the neighbourhood of the mouth, which may or may not persist throughout life. Living as it does in the cool waters of the ocean it must therefore have some other means of

preventing its warm blood from cooling, and to this end its whole body is encased in thick coatings of fat—the blubber.

The whale's nostrils are situated on the highest part of the head, and it is through these that it spouts or blows. The well-known spouting of the whale is nothing more than the act of breathing. The air in the lungs becomes heated and steamy and is ejected with considerable force when the whale rises to the surface, and condensing in the cold atmosphere it appears like a spray of water. Occasionally the whale starts to blow before it has actually broken the surface, in which case water is also driven into the air.

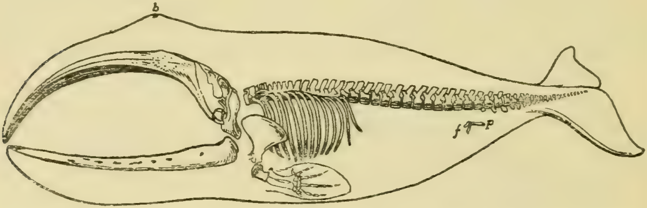


FIG. 21.—Outline and skeleton of Greenland Right whale (*Balaena mysticetus*) *b*, blow hole; *p*, hip bone; *f*, rudimentary thigh bone.

There are many different kinds of whales, but they may be divided into two main groups, the toothed whales and the whalebone whales.

The great Sperm whale is a good example of the toothed whales (Plate 42). Although there are no teeth in the upper jaw of the Sperm whale, or Cachalot, the lower jaw is well armed with twenty to twenty-five pairs of very sharp teeth. These teeth are most necessary for it feeds on a very formidable prey, the giant cuttlefishes or squids. Judging by the taste of the small common squid which is eaten on the Continent, the whale must feed on tasty morsels, but it has to capture a fearsome monster before it

Pl. 38. *H* 102.

Flying Fish (*Exocœtus spilopus*), $\times\frac{1}{3}$. (p. 98)

Cuttlefish (*Sepia officinalis*), $\times \frac{1}{3}$. (p. 106).

Pl. 39. *H* 103.

Squid (*Loligo Forbesi*), $\times \frac{1}{3}$. (p. 106).

can enjoy its meal. For some of these squids are several feet in length, with tentacles thirty or more feet long, armed with many powerful suckers. It needs a monster like the whale to tackle them, and many whales are caught with great scars upon their bodies that bear witness to the mighty struggles that have taken place in the deep waters of the ocean.

Among other toothed whales the Killer whales (*Orca gladiator*) are of interest, because they hunt in packs, feeding on fish and seals and even harrying the larger whales themselves. The common porpoise and the dolphins are also representatives of this group, the porpoises being among the smallest of the toothed whales.

The whalebone whales do not possess typical teeth. They have instead long thin plates of a horny texture, set close together all around the upper jaw. This is the baleen, or whalebone, that was once so fashionable in ladies' attire, but has now gone rather out of demand for that purpose. Each plate of whalebone is frayed out along its inner edge to form a mass of felted fibres (Plate 42).

With such teeth the whale obviously cannot prey on any powerful animal. It cannot bite or chew. Instead it feeds on the hordes of minute animals from a quarter of an inch to an inch in length, that drift in countless myriads in the waters of the sea and go to form part of that drifting community known as the plankton. Opening wide its mouth the whale takes in a great gulp of water with all its contained living animals. Then closing its mouth it raises its tongue and forces the water out through the whalebone sieve and the animals which remain behind are swallowed.

The Right whales (Fig. 21) are a typical example of this group, as are also the Humpbacks and Rorquals. Of these the Blue whale or Sibbald's Rorqual (*Balænoptera sibbaldi*),

may reach the immense size of eighty-five feet or more in length. The weight of such a whale would be over 300 tons.

Whales are distributed all over the oceans of the world, but while the toothed whales are to be found roaming throughout the central parts of the oceans where their prey, the squids, occur, the whalebone whales are chiefly confined to the cold Arctic and Antarctic waters and the coastal banks, where the drifting life on which they feed is most abundant. Many whales are stranded, dead or alive, from time to time along the coasts of the British Isles.

Little is known of the habits of whales, of their migrations, their breeding or of their growth.

Recently an interesting letter was published in *Nature* by Mr. R. W. Gray on the sleep of whales. It appears that whales are very rarely seen sleeping on the surface ; when they do so they lie motionless at the surface with their backs just awash and their blow holes just out of the water. But it is suggested that usually they sleep below the surface with their blow holes tightly closed, and this is quite possible seeing that they can remain beneath the surface for an hour or more when harpooned.

Seals

Other mammals that have taken up their abode in the sea are the seals, the sea-lions and the walruses. Unlike whales, which are unable to leave their watery home, the seals can move with considerable rapidity on dry land, although their gait can hardly be said to be gainly. Indeed all seals resort to dry land to bring forth their young, whether it be on sandy beaches, on rocks or on ice floes, and the young seals are said to be reluctant at first to enter the water.

There are many different species of seals, but only two are usually to be seen around British coasts, the Common

Seal (*Phoca vitalina*) and the Grey Seal (*Halichourus grypus*). Neither of these furnish the beautiful sealskin of commerce, this product only being obtained from certain distinct species known as " fur seals " or " sea bears."

Seals feed mostly on fish, and are commonly a nuisance in the estuaries of some of the Scottish salmon rivers, where they do much damage to the net fisheries for the salmon. Some species feed on shellfish and other small marine animals. The walrus uses its long ivory tusks for digging in the sand and gravel to turn up the shellfish on which it feeds.

Cuttlefishes and Squids

Amongst invertebrate animals there is only one group which can be classed as true swimming animals. These are the cuttlefishes and squids, which belong to the family known as Cephalopods. This name is derived from two Greek words meaning " head " and " foot," and originates from the fact that actually the feet or tentacles surround the head.

The Cephalopods belong to that main division of the backbone-less animals known as Molluscs, and are closely allied therefore to oysters, mussels and cockles, though admittedly the external resemblance is not obvious. In many ways they are the most highly evolved of the backboneless animals and are remarkable for possessing eyes similar in almost all respects to those of the higher animals such as fish and mammals.

Both the cuttlefish and the squid possess ten tentacles armed with suckers. Two of these tentacles are very much longer than the others and can be withdrawn into a cavity near the head. In this respect they differ from their near

ally, the octopus, which possesses only eight arms or tentacles, all of the same length.

Within the body is a curious flat shell, which serves to support the animal when it is swimming. In the cuttlefish this shell is hard and limy; it is that white object which we so often find cast up amongst the drift weed on the sea shore, and which we put to such various uses as removing ink stains from our fingers and giving to canaries to sharpen their beaks upon (Plate 32). In the squid, however, the shell is very thin and transparent and is commonly known by the fishermen as a "pen" on account of its resemblance to the old-fashioned quill pen of our ancestors (Plate 32).

Both animals are active swimmers. Usually they move slowly along by a slight wavy motion of the fins, which run along the sides of their bodies; but they can also dart rapidly backwards. To secure the necessary propulsion they draw water into their body cavities and then squirt it out with considerable force through an opening under the head.

Both the cuttlefish and the squid have within their bodies a little sac containing a black inky powder. This is the sepia that is used in the manufacture of certain brown paints. When alarmed or attacked by an enemy this ink is squirted out into the surrounding water, where it spreads out into a great dark cloud behind which the animal darts rapidly away and so eludes its foe. This method of escape is exactly that used by our battleships when they send out masses of black smoke to form a smoke screen, which drifts out between themselves and the enemy and so hides their movements.

In appearance the cuttlefish is stumpy compared with the squid, whose body is long and tapering and carries a big triangular fin along its hinder end (Plate 39). In our coastal waters none of the species that occur reach much

more than a foot in body length, but there are some species living out in the deep oceans that are veritable giants of their kind. These monsters may have bodies several feet in length and tentacles thirty or forty-feet long. To add to their horror each of the powerful suckers ranged along the tentacles is armed with a cruel hook, which can tear the flesh of any prey on to which it fastens. These huge squids, which live in the dimly-lit layers that overlie the cold, black abyss are very rarely seen, and still more rarely caught. But we can catch them indirectly, for it is on these that the Sperm whales feed, and in the stomachs of the whales can be found many remains of these squid, especially the hard, chitinous, beak-like jaws.

Sea Serpents

If the sea serpent really exists surely it can be safely classed as a swimming animal! It is fitting then to conclude this chapter with a few words about this interesting beast.

We can safely say that nearly all the accounts that have been given about sea serpents have been due to mistaken identity. The giant squids mentioned above are probably the main cause of many of the stories that have arisen. These monsters are known at times to come to the surface. What more like a serpent than one of these wriggling arms, thirty feet in length, writhing one moment on the sea surface, and the next raised aloft far out of the water. In many descriptions the serpent has been said to have been spouting water, an act quite to be expected of a squid.

Other objects that have been suggested to have given the appearance of a serpent are many and varied. Amongst these are a string of porpoises, two Basking sharks (it is a common habit for these sharks to swim in pairs one behind

the other), long strings of weed, the giant Ribbon-fish, and even a flight of birds in single file just above the water.

There are real sea snakes, most poisonous inhabitants of certain tropic seas ; but these seldom reach a length of more than two or three yards, and although they are indeed sea " serpents," they are not the sea serpents that we all hope it may be our lot one day to see. There is, however, every possibility that some beast worthy of all that the name implies may still exist in the great depths of the ocean. When we imagine the vast space of the undersea world, stretching for thousands of miles, north, south, east and west, we realize that there are possibilities for the existence of many fearsome monsters ; creatures so powerful as to evade all capture. Of the many tales that have been told, most of which can be almost definitely shown to have arisen through mistaken identity, one at least is worthy of mention.

In 1906 two naturalists, Messrs. Meade-Waldo and Nicoll, described in the Proceedings of the Zoological Society an animal that they had seen while cruising on December 7th, 1905, in the Earl of Crawford's yacht, the *Valhalla,* off the coast of Brazil. They say : " At first all that could be seen was a dorsal fin about four feet long, sticking up about two feet from the water ; this fin was of a brownish-black colour and much resembled a gigantic piece of ribbon sea weed." Behind the fin under the water could just be made out the form of a considerable body. " Suddenly an eel-like neck about six feet long and of the thickness of a man's thigh, having a head shaped like that of a turtle, appeared in front of the fin." Unfortunately, this curious beast soon disappeared from view and all that may have been seen of it again was on the next night when an animal, which they assert was not a whale, was making such a

commotion in the water that it looked as if a submarine was going along just below the surface (Fig. 22).

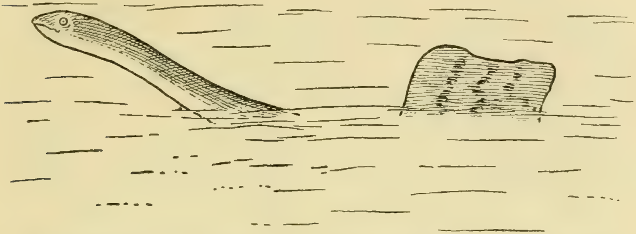


FIG. 22.—Sketch of an unknown marine animal seen off the coast of Brazil.

Maybe one day the sea will yield up this, its greatest secret. Maybe not.

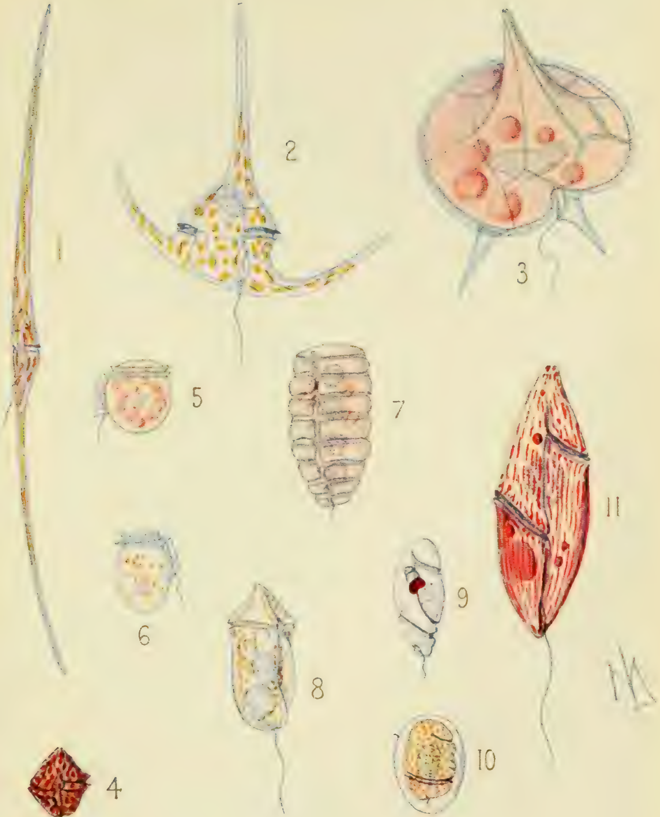
CHAPTER V

Drifting Life

WE have dealt so far with those animals and plants which live either on the sea bottom, or swimming actively through the water above the bottom. There is yet another community of organisms in the sea whose existence is, perhaps, not generally realized. It consists of countless numbers of animals and plants which drift about in the water layers at all depths between the sea surface and the bottom, at the mercy of tide and current. They are nearly all small, most of them minute, and many only visible under the high-powered microscope.

It is extremely easy to demonstrate their presence ; it is merely necessary to drag through the sea for a few minutes a small cone-shaped net, or "tow-net" (Plate 96), made of fine muslin, cheesecloth or silk ; or, if one is on an ocean liner, it is even possible to obtain them by hanging a small muslin bag under the salt water tap in the bathroom and just letting the water run.

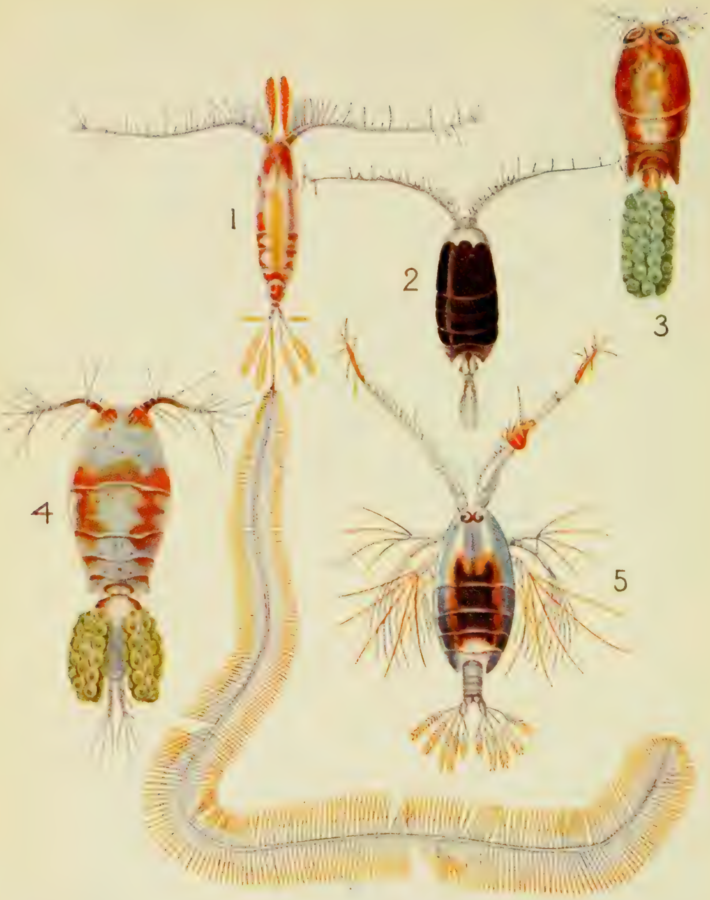
At times this drifting life is so abundant that it colours the sea for miles around. Such expressions as "red water," "yellow water," and "green water," are used by fishermen, who become wonderfully expert at deciding where to shoot their mackerel or pilchard nets by slight differences in the tint of the water that landsmen would not notice. In every case the characteristic tinge given to the sea is known to be due to the presence of certain kinds of organisms in innumerable quantities. Darwin



Pl. 40. DEL. M.V.L. *H* 110.

Dinoflagellates, ×ca. 200. (p. 114).

1. *Ceratium fusus.* 4. *Goniaulax polyedra.* 7. *Polykrikos Schwarzi*
2. *Ceratium tripos.* 5. *Phalacroma rotundatum.* 8. *Gymnodinium Lebourii*
3. *Peridinium depressum.* 6. *Dinophysis acuminata.* 9. *Pouchetia polyphemus*
10. *Cochlodinium Schuetti.* 11. *Gyrodinium britannica.*



Pl. 41. *H* 111.

Mediterranean Copepods. (p. 17).

1. *Calocalanus plumulosus*, × 20.
2. *Candace ethiopica*, × 8.
3. *Corycaeus venustus*, × 30.
4. *Oncaea mediterranea*, × 30.
5. *Pontellina plumata*, × 17.

in his *Voyage of a Naturalist* noted such discolouration, and mentions passing through two patches of reddish-coloured water, " one of which must have extended over several square miles." " What incalculable numbers of these microscopical animals ! " he exclaims. " The colour of the water, as seen at some distance, was like that of a river which has flowed through a red clay district ; but under the shade of the vessel's side it was quite as dark as chocolate. The line where the red and blue water joined was distinctly defined."

" Stinking water " is another expression used by fishermen, and in this case also a characteristic odour is given to the sea by the presence of hordes of certain organisms.

Many of these small drifting creatures, in fact almost all, are capable of emitting a phosphorescent light. It is these that make the sea sparkle with little glowing points of fire when we dip our oars into the water on a dark night. Occasionally, some phosphorescing animals will swarm together in such countless numbers that on calm still nights the whole sea surface seems to glow with a pale cold light.

Darwin again describes such a sight in picturesque terms. He says, " While sailing a little south of the Plata on one very dark night, the sea presented a wonderful and most beautiful spectacle. There was a fresh breeze, and every part of the surface, which during the day is seen as foam, now glowed with a pale light. The vessel drove before her bows two billows of liquid phosphorus, and in her wake she was followed by a milky train. As far as the eye reached the crest of every wave was bright, and the sky above the horizon, from the reflected flare of these livid flames, was not so utterly obscure as over the vault of the heavens."

Nearly fifty years ago the word " plankton "* was used by a German professor to embrace all this drifting life,

* (Gk. πλαγτος, wandering).

and the word is now in general use among those interested in the science of the sea.

Plankton Plants

One naturally wishes to know what kinds of creatures these are that make up the almost infinite multitudes that drift freely throughout the water layers. The plankton is now known to play a part of the greatest importance in the economy of the sea, and in this respect the organisms that deserve our first consideration are the microscopic plants. These are not like the plants on land, but consist generally each only of a single cell ; nevertheless, they are plants in the true sense of the word, because each contains within its cell colouring matter closely similar to that so characteristic of our land vegetation. These little plants are known as "diatoms" ; they are so called because they have, surrounding their cell-walls, glass-like protective shells composed of two halves—two lid-like structures that fit one into the other, and thus enclose the body of the plant in a little box.

In order to catch these diatoms it is necessary to use a net made of the finest muslin or silk, as they are, mostly, so small that they will pass through the meshes of ordinary coarse muslin. The catch, to the naked eye, will look like a greenish-brown scum, and if placed under the microscope will be seen to consist of a jumble of interlacing spines amongst which may be noticed green oblongs, squares and circles. To find out the true nature of the catch it must be diluted with sea water and only a drop examined, when it will be found that the diatoms are much fewer in number and separated one from the other so that their true structures can be made out. Some will be like little circular discs, others oblong with little spines or horns projecting from each corner, and others strung together to form chains of tiny

boxes covered with delicate, interlacing, hair-like projections. On Plate 88 are given drawings of some of the commonest diatoms that would be found in any catch from the northern and more temperate regions of the Atlantic Ocean and the seas around its border. There are many thousands of different species occurring in the world, and this is no place to confuse the reader with a medley of Latin names. For those who may take a deeper interest in making the acquaintance of the different kinds of diatoms and who find delight in observing the marvellously delicate and beautifully designed structures of these minute plants through the microscope, a list of literature will be found at the end of this book.

In addition to the diatoms there are other single-celled organisms that help to swell the plant life of the drifting community. They are especially remarkable because, besides containing the colouring-matter of plants, they possess two tiny structures like the lashes of a whip which by vigorous waving motion serve as a means of propelling the creature through the water. Now, a true plant derives all its nourishment from gases and dissolved salts that are absorbed through the cell walls ; it never takes in solid particles of food as an animal does. Many of these little creatures, which are called "peridinians," have no colouration and are able to swallow solid particles of food through a small depression on their cell surface. There are, however, a few which possess colouring matter and also swallow solid particles ; because they are able to feed like plants, and at the same time utilize solid food like animals, they are a continual source of bickering in scientific circles, the botanists claiming them as plants and the zoologists maintaining that they are animals !

Many of these peridinians consist only of a little naked cell with its whip-like lashes, and are in consequence,

extremely delicate and easily destroyed by the net; others, however, possess wonderfully designed skeletons made up of little plates which may carry spines and wings, giving the plants a beautiful appearance (Plate 40). Some of these peridinians are the cause of the coloured water mentioned above. The Goniaulax figured in Plate 40 has been known to occur in such profusion as to colour the water red, and another species has been reported to be so thick that when they died and decayed they caused the death of great numbers of fish.

There is yet another group of plankton plants known as Coccospheres. These also are unicellular but are characterized by the presence of numerous calcareous plates embedded in the cell, the different shapes of which serve as a means of identification of the numerous species.

These three groups, the Diatoms, the Peridinians, and the Coccospheres, are the most important constituents of the drifting plant life. The Diatoms are most abundant in the colder waters of the temperate and polar seas, while the two latter are characteristic of the warm waters of tropical and sub-tropical regions.

These plants are at times extremely abundant; they have often been reported to be so thick in the Baltic that a thimbleful of water would contain more than a thousand individuals. Were it not for these countless myriads of small plants we can safely say that the great oceans and seas of the world would be valueless to us as reservoirs from which to draw much of our food in the form of fish and other edible marine animals, for the small plants of the plankton are indeed the pasturage of the sea. They form the food of millions of small animals living in the drifting community on which larger animals prey. On land, man and beast alike are ultimately dependent on the grass and herbs of the field for food, the animals which feed on the

grass being eaten by man ; so also in the sea, the ultimate food supply is to be found in the drifting microscopic plants. But, whereas on land the plants are substantial and can be directly eaten by large animals, in the sea they are minute and are first eaten by the small drifting animals, which are in turn swallowed by larger creatures, and so on until, eventually, the fish forms food for man. In fact certain chemical constituents of our food have been traced to these tiny plants. To most the word "vitamin" is well-known. It is the name given to certain chemical bodies, which, although present in minute quantities only in our food, appear to be essential to our health and well-being. Their absence is thought to give rise to such diseases as scurvy ; and fierce controversy has raged over the desirability of eating white or wholemeal bread. Cod-liver oil also contains a certain vitamin which is thought to be partly responsible for its great medicinal value. The presence of this vitamin has been traced from the liver of the cod to the insides of the capelin (*Mallotus villosus*), a little fish that forms a large portion of the cod's food, and the swarms of which bring the cod together in vast shoals on the Newfoundland banks. From the capelin it has been traced to the minute animals on which it feeds, and so to the diatoms which nourish them. It is in these little plants—the diatoms—that the vitamins are made.

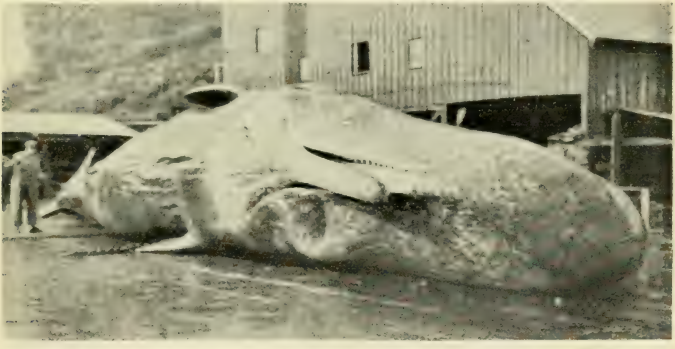
Plankton Animals

We have mentioned above that the drifting plants form the chief food of the small animals of the same community. Of what is this animal population chiefly composed ? Actually almost every group of the invertebrate animal kingdom has representatives in the plankton. In addition, the young of many kinds of fish live for a shorter or longer period a free, drifting existence. But of far the greatest

importance in the animal plankton is a group of crustacean organisms known as " copepods " or " oar-feet." They are all small, the largest being under half an inch in length. While there are very many species included in the group of copepods there is one that stands out far before all others in numbers and in importance in the chain of food organisms that links the fishes with the drifting plants. This little animal is unfortunately unknown to most people, because it can only be caught with the aid of a tow-net, and when captured is so small that it is regarded as insignificant. But if ever an animal merited attention it is the small copepod which goes by the Latin name of *Calanus finmarchicus* (Plate 45). It is unfortunate that it has no real popular name of its own ; but we shall call it in these pages " Calanus " for short, in the hope that some day Calanus will be just such a common every-day expression as shrimp, crab, or prawn.

Calanus is an inhabitant of the cold northern waters, where it forms one of the chief items of food of that most important of all food fish, the herring, and is even sufficiently abundant to aid in the building up of the enormous bodies of two of the Atlantic species of whales, one of which has been described as having been seen " in still weather, skimming on the surface of the water to take in a sort of reddish spawn or brett, as some call it, that at times will lie on the top of the water for a mile together." The spawn or brett is, of course, the little copepod, Calanus, which occurs at times in such swarms as to colour the water, whence it has acquired the name from fishermen of " red feed." It will give you some idea of the numbers of these little creatures if two examples are given of exceptionally heavy catches. In the Gulf of Maine, by towing a conical shaped net with a circular opening of one metre diameter behind the boat for fifteen minutes, over 2,500,000 Calanus

Portion of whalebone showing fringed margin *(Balaenoptera borealis)*, $\times\frac{1}{2}$. (p. 103).



By permission of J. T. Nichols.

Pl. 42. *I* 116.

Sperm Whale. (p. 102).

Pl. 43. DEL. M.V.L. *I* 117.

Zoea Larva of Edible Crab (*Cancer pagurus*). 40. (pp. 73, 12.).

have been caught, or enough to fill ten pint-tumblers solid. Again, near Iceland, 200,000 have been recorded from a five minutes' tow.

There are many other species of copepods but none to compare with Calanus in importance, although many far excel it in beauty, especially some of those that come from warmer and more tropical climes. Some of these are equipped with the most beautiful array of feathery spines; others are iridescent and shine with all the colours of the rainbow (Plate 41).

But next in importance as food for other marine animals, if not perhaps the most important, are shrimp-like animals that, like Calanus, are rarely seen and almost completely unknown to the world in general. These are known as euphausiids, or "krill," as they are called by the Norwegians. They are about an inch and a half in length, but are so abundant that they form a large part of the food of many of the northern fishes, and are the chief food of nearly all of the whalebone whales. Their bodies are quite transparent except for the presence of minute red spots, and they possess enormous black eyes and on this account the fishermen of the west coasts of Scotland call them "Suil dhu" or "black eye" (Plate 45). But they are most remarkable because along the sides of their bodies are numerous little organs that can blaze up into brilliant phosphorescence at will. More will be said about this phosphorescence under Chapter VIII, but suffice it to say that it has been recorded that with six of these little animals in a jar of water, flashing on their lights, it is just possible to read newspaper print!

There are, besides, many microscopic, single-celled animals dwelling in the drifting community. Of these, perhaps, the group of animals known as Radiolarians are of the greatest interest. These little unicellular creatures

are noteworthy for possessing solid skeletons on which their protoplasm is supported. Although these skeletons are so minute, they are fashioned in the most beautiful and symmetrical patterns. Almost every conceivable shape is to be found among them, and a few forms from bottom deposits are figured in Plate 21.

Another unicellular animal that is very commonly found is the Globigerina, which builds a calcareous shell made up of a number of connecting compartments (Plate 21).

So abundant are these two groups, the Radiolarians and the Globigerinas, in certain parts of the ocean, that when they die their skeletons, sinking to the bottom, form characteristic deposits. These are the Radiolarian and Globigerina Oozes mentioned in Chapter III; in certain localities also Diatom Oozes are formed from the rain of siliceous frustules, the skeletons of the dead diatoms.

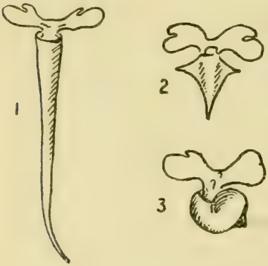


FIG. 23.
Pteropods or Sea butterflies.
1. *Creseis acicula.*
2. *Clio pyrimadata.*
3. *Limacina retroversa.*

Enough has been said of the most important members of the animal plankton. Let us now consider some of the more grotesque and unusual forms. Ordinary shellfish or molluscs are heavy lumbering creatures; yet there are some members of this group of animals that are delicate enough to drift about in the water layers amongst the plankton community without fear of sinking rapidly to the bottom. They are the sea butterflies, a most fascinating group of marine organisms. Perfectly transparent, some carrying a delicate paper-like shell, they move through the water by the rapid flapping of what appear to be wings. These wings are in reality

modifications of the "foot," that solid uninteresting mass on which most shellfish creep (Fig. 23). These animals are also so numerous in some parts of the ocean that their empty shells form deposits on the sea floor, the Pteropod Ooze (see page 56).

It is a characteristic of nearly all the plankton animals that live in the upper layers of the sea, that they are almost transparent. If one looks at a tow-net catch that has been

FIG. 24.
Sagitta (x 2).

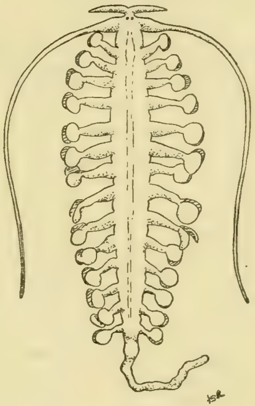


FIG. 25.
Tomopteris (x 2).

placed in a glass jar full of sea water, it is at first very hard to see the various animals on account of their transparency. A very common creature in the catch is the "arrow worm," or Sagitta (Fig. 24); this is thought to be a relative of the true worms, like the rag-worm, although it is very unlike them in appearance. It looks just like a little glass rod about three-quarters of an inch in length; but for all its apparent delicacy it is a very voracious creature. Sur-

rounding its mouth, are a number of powerful hook-like teeth, and with these it can seize on its prey, which it rapidly devours. Often it can be seen to have within its stomach one or two of the copepod Calanus, and, when very young herring are abundant, it will capture them and eat them even though they be as long as itself.

Another very beautiful plankton worm is the Tomopteris, which has a row of wing-like feet down either side of its body, with which it paddles its way through the water with a curious wriggling motion (Fig. 25).

In warm ocean waters there are commonly to be found numbers of animals known as Salps. These are closely allied to the common sea squirts, which lead a sedentary existence fixed to rocks and piers; but unlike its relative, the Salp lives a free drifting existence in the open waters. It is an inch or more in length, shaped like a barrel, and perfectly transparent. They are not usually to be seen in northern waters, and when found are a fairly reliable indication of the presence of Gulf Stream water.

Belonging to the same group of animals is the Pyrosoma, so remarkable for its phosphorescence. The Pyrosoma suffers a curious indignity at the hands of a small crustacean, the Phronima, a glass-like creature, all head and eyes. The Phronima eats off all the living portion of the Pyrosoma (which is really a colony of animals) and then retires inside the barrel-like skin that is left (Fig. 26). This interesting beast is sometimes to be seen within its gelatinous home, surrounded by a brood of young, and has been observed to navigate its home about in the water.

But the members of the plankton are too numerous to mention here. The best book is nature itself, and therefore at the first opportunity one should make a small tow-net, take a small boat and row out about a mile from the shore on a calm day, drop the net overboard until it is a few feet

Pl. 44. DEL. M.V.L. *I* 120.

Megalopa Larva of Edible Crab *(Cancer pagurus)*, ×30 (p. 123).

The Crustacean Copepod *(Calanus finmarchicus)*, × ca. 12. (p. 116).

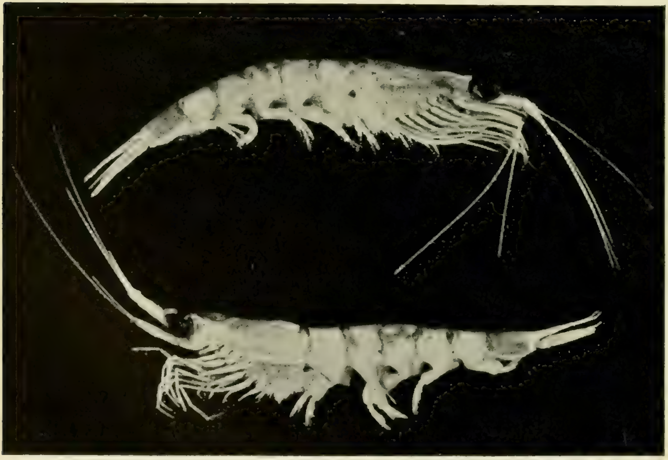


Photo. by Fleming.

Pl. 45. *I* 121.

Krill, a Crustacean Euphausiid *(Meganyctiphanes norvegica)*. Natural size. (p. 117).

below the surface, and then tow it slowly along for a few minutes. The catch will be sufficient reward for the trouble and the sight of the delicate creatures will open one's eyes to the amazing abundance and diversity of this drifting life that peoples the sea in every region of the globe.

The few animals that have so far been mentioned constitute part of what is known as the " permanent plankton," that is, they live as drifting organisms for the whole of their lives. There are yet other members of the plankton which have adopted this mode of life for only a short period in their life-history. In the coastal regions nearly every

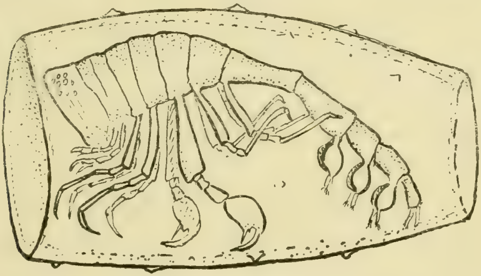


FIG. 26.—Phronima in dead Pyrosoma (x 3).

animal we find has at some time drifted freely and aimlessly about in the water layers above the bottom. The young of all the smaller marine animals are, when first they hatch from the egg, extremely small, and in consequence have insufficient swimming power to cover large distances, and are unable to cope with the tides and currents. At this stage, they rise up from the bottom, if hatched there, and become members of the plankton. Here they will remain for shorter or longer periods, growing and developing until such time as they have assumed their adult characters

or are large and strong enough to seek for themselves their natural home on the bottom.

Worms, starfish, crabs, lobsters, oysters, sea squirts and even the majority of fishes in the sea, spend the first days of their lives drifting about in this manner (see Plate 91). One of the main advantages of this mode of life is that it ensures complete dispersal of the young. Many marine animals live fixed to the rocks and bottom, such as hydroids and mussels, or are at most very sluggish and do not move far afield It is obvious, therefore, that if their offspring were born and hatched " at home " the parental abode would soon become so crowded with young and half-grown children that there would be no room to turn. But if the children are sent out to fend for themselves in the upper water layers they will be carried far and wide by the currents, and those that survive will settle to the bottom many miles from where their parents lived.

These drifting young of many marine animals are very different in appearance from their parents ; indeed, it is safe to say that if they were shown to a novice it would be impossible for him to say into what they would grow. Because of these extraordinary differences between adults and young, the early stages of many marine animals, when first discovered by naturalists in the plankton catches, were regarded as new species of animals and described and given names of their own. It was only by rearing them, or piecing together successive stages in the life histories from the catches, that the adult into which they were going to develop could be discovered. Who, for instance, without knowing beforehand, would dream of suggesting that the little animal figured in Plate 43 was the young of the common edible crab ? When first discovered it was not recognized as such and was given the name " Zoea," on this account it is now known as the zoea stage of the crab. After

hatching, the young crab remains in this stage for some time during which it undergoes several moults. Finally, it suddenly moults into a stage quite unlike the zoea and more like the adult crab; albeit when first found it was not recognized as such and was labelled "megalopa" (Plate 44). From this stage it moults into a perfect little crab. So we see that in the life-history of one animal, the crab, the successive stages are so different that no less than three animals have been thought to exist, the zoea, the megalopa and the crab, which were in reality all crab.

These animals which appear for only a short period in the drifting community form the temporary members of the plankton, and their appearance in the upper water layers depends, of course, on the times at which the parents spawn, and this gives rise to the seasonal changes in the plankton mentioned on page 244. It is chiefly in the coastal regions that these temporary drifters are found because of the great wealth of bottom life in the shallower regions.

Distribution of Plankton

Having given the reader some idea of what composes this drifting life or plankton, let us now examine what is known of the distribution of the plants and animals that form it in the sea.

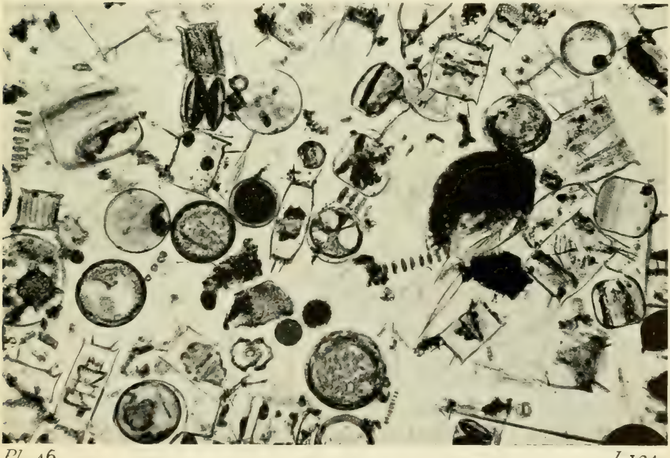
To begin with it must be realized that besides the immense horizontal area of all the oceans and seas of the world, all of which are inhabitable, the waters also have a considerable depth, the average of which is as much as two miles. Seeing then that organisms that live in the water layers themselves are free to move up and down, as well as in a horizontal direction, it is evident that we have two types of distribution to deal with, namely, horizontal or geographical distribution, and vertical or depth distribution.

Much work has been done on the geographical distribution

of the animals and plants of the plankton by large oceanographical expeditions which have been sent out by different countries during the last fifty years, and it is fairly established that all the waters of the globe are inhabited by them. Just as on land, the various species of plants and animals have their own distribution, some living in tropical climes and others in the far north or south, so it is noticed that many members of the plankton are to be found only in certain regions and may give the catches made in those localities a characteristic appearance. Amongst diatoms, for instance, there are species that are normally only found in coastal regions, others that occur only in the open ocean waters of tropical and sub-tropical regions, and others again that characterize the catches of northern waters. But while species of these little drifting plants are to be found almost anywhere in the oceans all over the world, the cool temperate and the cold arctic and antarctic waters are now known to carry this diatom life in quantities far exceeding the other regions. The waters that bathe the shores of the British Isles, of Holland, Sweden, Denmark, Norway and Iceland, on the east, and of Greenland, Newfoundland and the Gulf of Maine in America on the west, possess a richer pasturage of microscopic plant life than is to be found in any other locality in the North Atlantic Ocean. The significance of the plankton plants in the general economy of the sea will then become at once apparent, when it is realized that it is precisely these regions, the North Sea, the Baltic, the Norwegian and Greenland Seas, and the banks of Newfoundland, that give rise to the greatest fisheries in the Atlantic, and in fact in the whole world.

Dependent on the diatoms are, of course, the small animals of the plankton, and it is natural to suppose that where the plant life is most abundant there will be found

Dinoflagellates *(Ceratium tripos)*, ×ca. 20. (p. 114).



Pl. 46. *I* 124.

Spring Diatom Plankton ×44. Chiefly *Coscinodiscus* and *Biddulphia*. (p. 113).

Pl. 47. *I* 125.

Chart showing distribution of Plankton in North Atlantic.

Darkest green, most abundant. Blue, scarcest.

(p. 126).

the greatest quantities of animal life. Such indeed is the case. The abundance of that little creature, the Calanus, and of the shrimp-like euphausiids, has already been dwelt upon and they too are to be found chiefly in the regions outlined above.

But, while the plankton is present in greatest quantities in these northern waters, it is remarkable that compared with the plankton of the warm and tropical regions the numbers of different kinds of animals are extremely few. The catches made in the northern waters can almost be described as monotonous in composition, that is, although they are so large, they will be made up of only comparatively few species of animals. To the collector then the catches made in warmer regions prove vastly more interesting on account of the wealth of different species to be found there, even though they be present only in small numbers. One example is sufficient to show how marked this difference is. Of roughly three hundred species of copepods, while eighty per cent. are to be found in the warm regions, only five per cent. are found in the cold northern region and only two per cent. in the southern. This phenomenon holds good for all the different groups of animals represented in the plankton.

Apart from the excessive abundance of drifting life in the colder waters, it is to be noticed that everywhere the coastal regions are considerably richer than the waters of the open ocean. The central regions of the North and South Atlantic oceans are the poorest in plankton life, that is the areas lying a little north and a little south of the equator. Actually in equatorial regions the plankton is a little richer. The deep blue Sargasso Sea, in the centre of the North Atlantic, is probably as barren as any region in the world. There are several factors that together are responsible for the abundance or poverty of plankton life, but of greatest importance is the presence or absence of

certain nutrient salts dissolved in the water on which the drifting plants depend for their growth. In localities where these bodies are richest the plants will be most abundant, and, consequently, the animals which depend on them for their food supply. A discussion giving the basic principles that underlie this plankton production will be found in Chapter XI ; it would be out of place to enlarge on the problem here until the reader has made himself acquainted with some of the properties of sea water that are outlined in Chapter X.

In Plate 47 is given a chart of the North Atlantic Ocean and surrounding seas, in which the density of plankton life is shown diagrammatically. The richest areas are shown by the green colouration, the regions of greatest density of life being the deepest green. The green colour gradually shades off into blue which can be taken to represent a poverty of plankton organisms.

Having dealt with the geographical distribution of the plankton, let us turn now to consider at what depths this drifting life is to be found and where it is most abundant. Taking the plants first, consisting of the Diatoms and the Peridinians, collections made by research vessels from different depths show that it is only the upper water layers of the sea, from the surface down to about one hundred fathoms, that contain drifting plant life in any quantity.

A moment's thought will satisfy anyone that this must of necessity be the case, since all plants are dependent on the sun's light for their life and the deeper we go into the water the less light is there present. In fact it has been shown that at little more than ten fathoms in the English Channel off Plymouth the amount of light present is already similar to that in the heart of an English wood. In the clearer open waters of the ocean the light can perforce penetrate deeper, but it is certain that at a depth of one

hundred fathoms it is already so dim that few plants can live in a healthy condition. More will be found on the subject of the light beneath the sea surface in Chapter X. Although there is a depth limit at which the normal life of the plant becomes impossible, yet at times collections may show their presence at still greater depths, the likelihood is however that these plants will be in a dying condition and will have sunk to those depths under their own weight.

Now animals, as we know, are not so dependent on light directly ; in fact there are many animals on land that seem to prefer darkness and are nocturnal in their habits, shunning the light of day.

The same applies to the sea animals, there are many that live in the dark deep layers ; in fact, recent research has shown that there is no depth at which some plankton organisms do not exist.

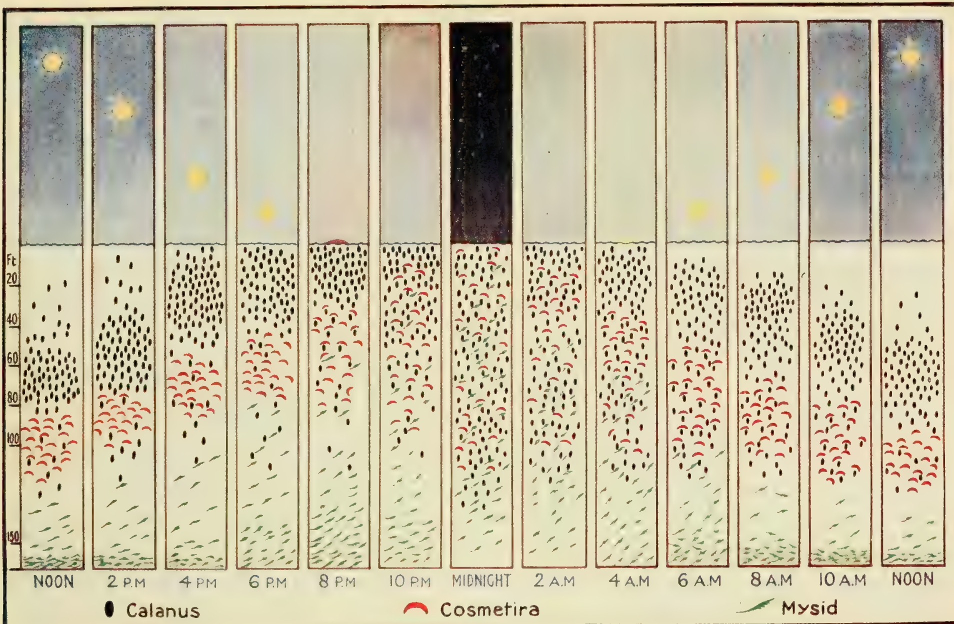
All the animals are not, however, found evenly distributed in the water layers from top to bottom. Each animal seems to show a definite preference for some particular depth region ; for instance, there are some that live always in the upper fifty fathoms or so, rarely penetrating to deeper levels ; others again will never be caught between one hundred fathoms and the surface, but always live deeper. On account of these differences in depth distribution, exhibited by the various animals of the plankton, we find that catches made from different levels are each quite characteristic and distinct one from another in their composition, in the same way that collections from different geographical regions are each characterized by the presence of those organisms that are prevalent in the locality in which the catch was made.

It is a general fact that in the daytime the animals that live in the layers quite near the surface are very few, this is especially the case in the summer months. For instance,

off our coasts it is necessary in the daytime to fish at a depth of ten to fifteen fathoms in order to get the largest catches. In the open ocean the depths at which the greatest assemblages of plankton animals are found are generally considerably deeper. Now, as has been said, this is the case in the daytime ; but it is a remarkable fact that at night matters are quite different, and a curious change comes over the plankton distribution. On the approach of dusk, just after the sun has set, all the animals begin to swim in an upward direction, so that by about nine or ten o'clock, in the summer months, the surface layers, so barren in the daytime, have been enriched by animals that have swum up from the deeper levels. In Plate 49 is shown the actual results of collecting at different depths in daylight and at dusk. It can be clearly seen that whereas in the daytime the layers down to about five fathoms are very poor in plankton compared with the deeper levels, at dusk the two upper collections are quite as large as the deeper ones. It will be noticed that the bottom catch at dusk is also greater than that taken in the daytime, this is because of the addition of large quantities of animals that have come up from deeper levels quite near the sea bottom ; in fact, there are certain small creatures that live actually on the bottom itself in the daytime which move upwards towards the surface at night ; they may never actually have time to reach the surface itself, because at dawn all the animals begin to move downwards again to take up their abodes at their usual day levels (Plate 48). We all know that the herring fishermen only shoot their drift nets at night. This is because at night, the herring, like the plankton animals, also come to the surface.

This phenomenon of upward movement at night, or vertical migration, throws considerable light on why the different animals prefer certain depths in the daytime.

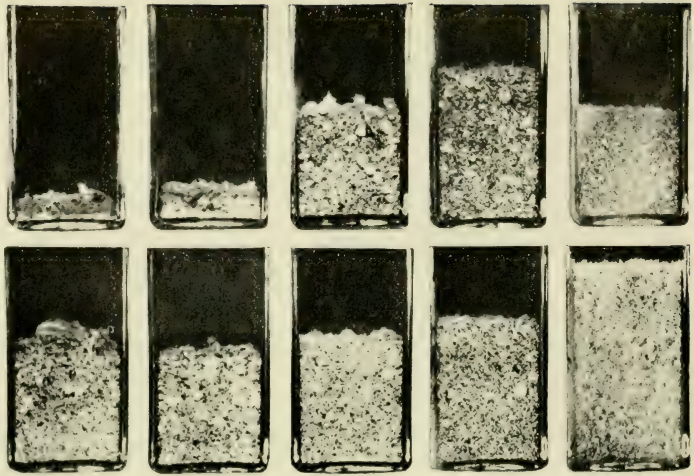
It seems almost certain that the causes of the up and



Pl. 48. DEL. F.S R. / 128.

Vertical Migration of Plankton Animals. (pp. 128, 129).

Showing behaviour of a crustacean copepod (*Calanus finmarchicus*), a medusa (*Cosmetira pilosella*), and a crustacean mysid (*Leptomysis gracilis*) which lives on the bottom in the daytime.



Daylight. 3.25 to 4.45 p.m.

Dusk. 7.55 to 9.17 p.m.

Surface. | 23 ft. | 46 ft. | 63 ft. | 100 ft.

Pl. 49. *f* 129.

Vertical Distribution of Plankton Animals in July. (p. 128).

Showing how in the daylight the surface waters are poorly populated, but at dusk they become filled up by the upward migration of animals from deeper levels.

down movements are the changes in the strength of light experienced by the animals ; this is further confirmed by the fact that many animals live deeper in the bright sunny days of midsummer than they do earlier in the year, when the light entering the water is not so strong. From this, then, we see that most of the plankton animals tend to avoid strong light and prefer the dimly lit conditions of the deeper layers ; at the same time all the evidence goes to show that each animal shows a preference for a certain strength of light to which it is adapted. Towards the evening they follow the "optimum" strength of light towards the surface as night draws on, but in the dark there is no light stimulus and they are free to move anywhere (see Plate 48) ; at dawn they once more pick up their optimum intensity and move downwards as the daylight strengthens. It is also a curious fact that the older an animal becomes the more it shuns the light, and it is generally the younger stages that are found near the surface. This is not, however, always the case ; the early stages of the Velella or "By the wind sailor" are found at very deep levels, while the adult, as mentioned below, floats right on the surface of the water, where it is blown hither and thither by the winds.

Adaptations for Suspension

In considering this drifting life it may have struck the reader that it is a curious thing that all these organisms, many of which, such as the diatoms, are practically incapable of any independent movements, should remain suspended in the water. Why do they not sink rapidly to the bottom of the sea ? The answer to this question rests in the demonstration of some of the most remarkable structural adaptations, which fit most of the plankton organisms to the conditions under which they live.

Their main requirement is that by some means or other

they should be able to maintain the level at which they are drifting. The means by which this capacity is attained are many and varied, the general aim being to reduce the organism's specific gravity directly until it is the same as or less than, that of the surrounding sea water, or to obtain a similar effect in a more indirect manner.

Species that have achieved the power of becoming lighter than water are comparatively few in number. The chief examples occur in a group of jellyfishes known as Siphonophores. The name of the Portuguese Man-o'-War, a stinging jellyfish, is well-known to all. This animal possesses a specially designed " float " into which gas is secreted by a specialized gland. This gas-filled reservoir projects above the surface of the sea and acts as a sail, by means of which the wind blows the jellyfish along, transporting it from place to place with tentacles extended in all directions ready to seize any unwary prey that they may touch, instantly paralysing it with their batteries of stinging cells. Another closely allied form is the Velella, or " By the wind sailor " (Plate 50). This likewise has a small gas-filled sail. The animal, when seen alive, is of a fairy-like delicacy, possessing this transparent, papery sail, situated above the centre of the body: on the under surface is the " mouth," centrally placed and surrounded by delicate mobile tentacles of a sky-blue tint. These little creatures, which reach a size of one or two inches in length, are natives of the warmer ocean waters and the Mediterranean. However, they are occasionally to be found stranded along the western and south-western shores of the British Isles after prolonged southerly winds, that have wafted them speedily along the surface of the sea from the warmer latitudes.

In order to reduce the specific gravity as nearly as possible to that of sea water, many animals make use of fats and

oils formed in their bodies. These oils, being lighter than water, tend to diminish the weight of the animals that contain them. Those round globules of oil mentioned on page 80 as distinguishing characters in the drifting eggs of so many fishes probably tend to help in keeping the egg suspended in the water (Plate 29).

But of all the modes of obtaining buoyancy the indirect methods of producing the same effect as a reduction in specific gravity are the most wonderful. If we drop a stone into water, and watch it sinking, we shall notice that its sinking speed is considerably less than if it were falling through air only. The speed is reduced by the frictional resistance set up by the stone as it moves through the water. This property of resistance to the movement of a body is known as "viscosity." Some liquids are naturally more "viscous" than others; they are said to have a high viscosity. Treacle is a very viscous fluid; many oils also are highly viscous. Thus the frictional resistance to a falling body would be greater in treacle than in sea water. Now, of course, the total frictional resistance experienced by a falling body depends on the amount of area exposed against the fluid through which it is moving. We know that a slate takes longer to sink flatways than if it is on edge. Clearly then, if the frictional resistance can be made infinitely great compared with the actual weight of the body itself, a stage will be reached at which it would counteract the force due to gravity and the body would no longer sink, but become suspended in the water.

The structure of many plankton organisms shows an attempt to increase the frictional resistance, which evidently succeeds in keeping the organism almost suspended in the water. Although they cannot completely counteract the effect of gravity they can, nevertheless, come very near it so that sinking is extremely slow.

The effect is brought about either by greatly increasing the surface area by means of long spines or feather-like projections, or by extreme flattening so that the creature is like a leaf and when lying horizontally in the water is prevented from sinking except at a very low speed. The spiny and hair-like processes on many of the plankton diatoms depicted in Plate 88 serve this purpose in nature. The diatoms themselves are so very minute that the many spines must increase their surface area comparatively to an enormous degree, and they become literally suspended in the water so slow is their sinking speed. The rate at which a diatom will sink through the water has been measured, and, of course, varies for the different species according to their shape. Let us take as an example a species of Chætoceros (Plate 88, fig. 3); this takes on an average about four and three-quarter hours to sink three feet, or eight minutes an inch. This was in still water, but in nature, near the sea surface, owing to wave action there are continual little swirls and eddies which will bring it up or down at a much faster rate than it sinks.

Now, the animals, of course, on account of their larger size and weight will sink considerably faster than plants, but they also possess the power of locomotion, by which they can regain their level. The presence of spines and feathery processes on the animals' bodies, by slowing down the rate at which they sink, prevents them from having to be continually on the move to keep up in the water. If a living plankton animal is watched it will be seen to make a rapid upward movement by swimming and will then rest while it sinks only slowly through the distance that it so rapidly moved up through.

An extreme example of flattening in an animal is to be found in the case of the larva of the common crawfish or rock lobster. This is, of course, a different species from the

Pl. 50. DEL. W.R. *K* 132.

"**By the wind sailor**" (*Velella spirans*), Natural size. (p. 130).

Pl. 51. DEL. F.S.R. K 133.

Larva of Rock Lobster *(Palinurus vulgaris)*, ×8. (p. 133).

lobster that is most eaten for food in the British Isles. It is the " Langouste," which is, however, much preferred as a delicacy by the French.

The larva is a most curious sight (Plate 51). The body, measuring about a quarter of an inch across in the oldest individuals, is quite transparent and flattened like a piece of paper, while the long feathery legs and projecting eyes stick out all round and effectively aid the purpose of the flattened body in preventing the animal from sinking through the water.

It is not necessary to resort to experiment to prove that these structures are an aid to suspension in the water. It is known that the viscosity of water varies with the temperature, a rise in temperature lowering the viscosity to a marked degree, so that the resistance the water offers to a body sinking in it is considerably lessened. If, then, an animal or plant lives normally in warm water it will need to be extra well equipped with hairs and spines compared with its cousins who live in cold waters.

Now, it is a remarkable fact that by the side of organisms from cold and temperate regions those from the tropics exhibit to a much greater degree these structural excrescences, making many of them bizarre and grotesque in appearance. It has even been found that the same species of Peridinian may differ from place to place in form. For instance, in two individuals of the same species, the one from tropical seas has very much longer horns than those of its relative from our own colder waters.

. . . . . .

In these few pages an attempt has been made to put before the reader some of the main features of that remarkable community of drifting life, the plankton. Their importance cannot be over-estimated and plankton study

forms a considerable part of modern investigations into the resources of the sea. This chapter has been devoted mainly to describing what the plankton is and where and how it lives, but in a future chapter will be given further information of the part played by these small organisms in the watery world, in the light of recent research.

CHAPTER VI

Boring Life

Of all the creatures which inhabit the sea, few are more interesting than those which bore into wood or stone and live within the burrows they construct. None certainly do so much damage as the wood borers, notably the dreaded Shipworm which, since the dawn of history, has been recorded as the cause of grave damage to wooden ships. The galleys of Greece and Rome in classic times, those of Venice in the Middle Ages, and Drake's famous *Golden Hind*, all were riddled with the burrows of the Shipworm which has even threatened, by its attack on the dykes, the very existence of Holland. Although in modern times the steel hulls of the majority of ships have nothing to fear from it, the Shipworm still does great damage to wharves and piers made of wood; so great indeed that both in this country and in the United States extensive investigations have been set on foot in the hope of discovering some means of combating its ravages and those of its accomplices.

Wood Borers

The wood borers may be divided into two groups, those which are molluscan and those which are crustacean. The former are the more important and we will consider them first. The Shipworm is the most outstanding of these for, in spite of its common name and naked, worm-like body, it is really a bivalve mollusc which has taken to a very extraordinary mode of life and become, as a result, very unlike

its relatives such as the cockle and mussel. When taken out of its burrow and examined, the Shipworm, as shown in Figure 27, is seen to consist of a long, naked body with at one end a pair of small, peculiarly shaped shell valves, and at the other a pair of delicate tubes or "siphons." The former is the front end of the animal, it lies at the inner end of the burrow and possesses the boring organs and the mouth. The siphons are the only part of the animal which projects from the burrow; they are instantly withdrawn when they are touched and the opening of the burrow—not much larger than a pinhead—is closed by the pushing forward of a pair of shelly, club-shaped "pallets" which are fastened to the hind end of the animal about the base

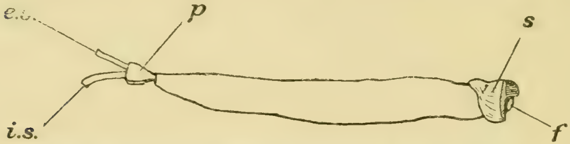


FIG. 27.—Shipworm (Teredo) out of burrow (slighly reduced); *e.s.* and *i.s.*, Siphons for taking in water; *f.*, foot; *p.*, pallets for closing opening; *s.*, shell.

of the siphons. Within the body the organs are greatly extended as a result of the elongated shape of the animal. The principal organs are near the front end, but along the entire length there stretches a cavity divided down the centre by a delicate lattice-work of tissue. Water enters the body of the animal through one of the siphons and passes into one of these divisions, it is then filtered through the lattice-work, leaving behind it any food particles which are carried to the mouth, passing into the second chamber from which it is expelled by way of the other siphon. In this way the animal obtains both oxygen for respiration and a certain amount of food.

Now let us consider how it bores its way through the wood. To understand this it is necessary to refer to Figure 28 which shows the position of the boring organs while they are in operation. Although many theories have been advanced on the subject, it is now certain that boring is carried out by the action of the small shell valves, which are specially adapted for this purpose. As shown in Figure 29, they are globular and can be divided into three regions, a hinder portion in the form of a broad wing which is known as the auricle, a middle portion which forms the

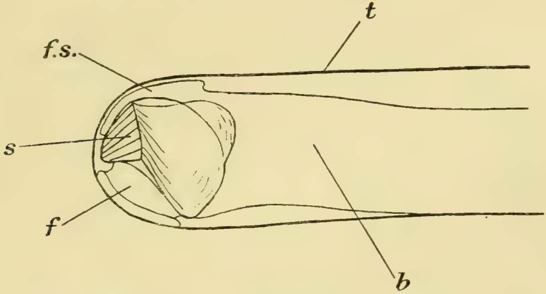


FIG. 28.—Head end of Shipworm (Teredo) lying in burrow; *b.* body of worm: *f.*, foot; *f.s.*, fold of skin above shell for gripping wood; *s.*, shell *t.*, edge of burrow.

major part of the shell, and a portion in front of this which only extends for less than half the width of the middle portion and is then cut away sharply at right angles. The surfaces of these two latter regions are covered with sharply-pointed ridges, those on the former passing diagonally across the anterior third of its surface, while those on the latter run parallel to the sharply cut lower margin. Transferring our attention to the inner surface of the shell, we see that there are two knobs, one at either extremity of the middle region, while from the upper of these there hangs

down a long process known as the apophysis. The two halves of the shell are attached by the two knobs so that the valves are able to rock backwards and forwards upon these two points, first the hinder and then the frontal regions coming closer to one another.

This rocking process takes place regularly in life, the motive power being supplied by two pairs of muscles, one of which runs between the hinder regions of the shell and the other between the frontal regions. From between

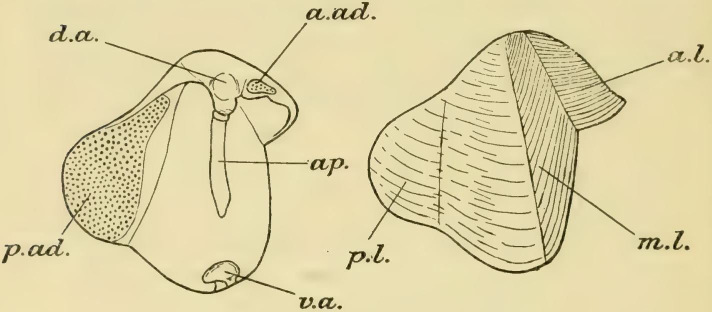


FIG. 29.—Shell of Shipworm (Teredo). Inner and outer views. *a.ad.*, and *p.ad.*, attachments of muscles; *ap.*, apophysis; *a.l.*, *m.l.*, and *p.l.*, parts of shell; *d.a.* and *v.a.*, articulating knob.

the valves in front there projects a little round sucker, which corresponds to the "foot" or organ of movement in such animals as the cockle. The muscles which work the foot are attached to the apophysis and by their contractions enable it to grip the wood at the head of the burrow as shown in Figure 28. At the same time a flap of skin which overlaps the shell above presses the animal firmly against the wood in that region. With the shell pressed tightly against the head of the burrow in this manner it is easy to see how boring takes place. By the contraction of

the hinder muscle, the frontal portions of the shell are drawn apart so that the sharp ridges with which they are covered scrape off the surface of the wood while at the same time the ridges on the middle lobe widen the opening behind. The small muscle between the frontal lobes now comes into play and by contracting in its turn brings the frontal lobes together again, which is a much easier operation because the surface of the wood offers no resistance to movement in this direction. The foot then loosens its hold and moves a short distance to one side, when the same process is repeated. This goes on time after time until the shell and front half of the body have twisted completely round—the hinder end cannot do this because it is attached to the burrow in the region of the pallets—when the movement is reversed. As a result of this continuous working of the shell and twisting of the front end of the body first in this direction and then in that, the inside of the burrow becomes perfectly smooth and circular in cross section. Immediately behind the shell the surface of the wood becomes covered with a layer of shelly substance which the animal produces in the naked region of its body. The whole process of boring is a model of mechanical efficiency which is not to be surpassed by any member of the animal kingdom.

The mouth of the Shipworm lies just above the sucker-like foot. Into it pass, not only the tiny particles collected from the sea water which enters through the siphons, but also the minute fragments of wood which are cut away by the boring organ. All of these have to pass through the gut of the animal before they can be discharged into the sea water by way of the second of the siphons. It has long been a matter of dispute whether the Shipworm can actually digest the wood or whether this passes through the body unchanged, but recent investigations seem to show quite definitely that the animal does obtain a considerable

amount of nourishment from the wood, the fragments of which are acted upon by digestive juices, and sugars produced which can be absorbed by the tissues. There is, moreover, a large extension of the stomach which is always filled with shavings of wood and seems to be well adapted for the storage of such a slowly-digested substance.

Once encased in its burrow no Shipworm can ever leave it. As we have seen the opening of the burrow is not much larger than a pinhead whereas, within, the burrow widens out quickly and may, in the common species, be some half an inch in width. Moreover, the animal is actually attached to the edge of its burrow in the region of the pallets. If a Shipworm is taken out of its burrow, no matter how carefully this is done, the animal cannot make a new burrow for itself. Since this is the case how does it happen that new wood becomes infected, as it does very quickly if conditions are favourable for the growth of the Shipworm ? During the spring and summer especially, the eggs and sperms are discharged in immense numbers into the sea by way of the second of the siphons. There the young Shipworms develop and at this early stage of their existence they are exactly like young mussels or similar bivalves. After a short time a pair of tiny shell valves appear which entirely enclose the body and from between which a crown of small hairs or " cilia " can be protruded by means of which the little animals are able to swim about, in exactly the same manner as the oyster (Fig. 59). This freely swimming " larval " Shipworm is shown in Figure 30. It is not known for exactly how long the Shipworms remain in this state, but they can probably do so for several weeks, and during this time they may be carried for great distances by ocean currents or wind drifts. This early stage in their existence is the only time when the Shipworms are able to move about freely in the sea and

when they are able to infect new timber. It has been shown by experiments that these larval Shipworms are attracted by wood or by an extract of wood made in alcohol or ether, and, as a result of this attraction, they remain on its surface should they chance to drift there, whereas they do not remain on any other hard surface such as stone.

Very soon after it has alighted on the surface of the wood, the larval Shipworm begins to change ; first of all it loses the crown of tiny hairs whereby it swims, developing in its stead a long, tongue-shaped organ or foot by means of which it moves about on the wood until it finds a suitable place to begin boring. This having been found, it commences operations, first, it is said, covering itself with fragments of wood or other particles. Both shell and foot are quickly converted into those of an adult Shipworm and the animal begins to bore its way quickly into the wood, the pallets and the siphons are formed and remain attached to the burrow near its opening while, as the burrow grows longer and longer, the naked body elongates until the long, worm-like appearance of the adult is gained. It is usual for them to enter the wood at right angles to the grain but they soon turn in the direction in which this runs and excavate a long burrow. However many animals there may be in a piece of wood, the burrows never run into one another, to avoid this they will twist and turn and interlace with one another in the most intricate manner, as an X-ray photograph of a piece of heavily infected timber shows extremely clearly (Plate 54). Owing to the small size of the openings of the burrows the wood may be heavily infected and show no in-

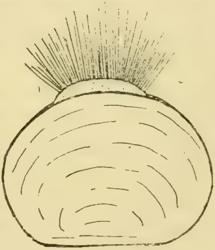


FIG. 30.
Larva of Shipworm (Teredo) greatly enlarged.

dication of this fact ; finally, however, it crumbles away (Plate 53). Shipworms do not live long, a year or perhaps two years. When they reach a certain age or when there is no further wood to bore into, they continue the shelly casing over the front end of the burrow and remain quiescent within this, taking such food as they can obtain from the water, until they die.

The action of the Shipworm in our own waters is much slower than that of the tropical species. Here, a piece of untreated wood is seldom attacked until it has been in the water for at least a year, whereas in the South Seas wood will become infected in a few weeks and after six weeks show a similar degree of infection to wood which has been exposed here for eighteen months.

There are many different species of Shipworms but they all belong to two genera, one called Teredo and the other Bankia. All the British Shipworms belong to the genus Teredo, of which three species are found in our seas, and none of them construct tubes longer than about eighteen inches, the majority much less, but there are tropical Shipworms which are much larger, one, the " giant Teredo," being reported to attain a length of two yards and become as thick as a man's arm ! The members of the genus Bankia are inhabitants of the tropics and are easily distinguished from Teredo by the structure of the pallets, which are paddle-shaped in Teredo but are long and feather-like in Bankia.

There are two other bivalve molluscs which live in wood. One, known as Xylophaga, is commonly found in floating timber in temperate seas, it has a shell very like that of Teredo and it bores in the same manner, but there is no elongate body, the siphons project from the hind end of the shell which completely encloses the body (Plate 52). The burrows are short, seldom more than one and a half inches

deep, and are not lined with shell. Although the burrows are apparently made in the same manner as Teredo, by means of the shell, there are no pallets and the animals cannot digest the wood. The same is true of the third type of Molluscan borer, Martesia. This is a native of the tropics and is very like a small mussel in appearance; its burrows are not generally more than two and a half inches long and one inch wide, i.e., the size of the animal which lives within them. Neither of these animals has attained the efficiency of Teredo as a borer and both seem to seek the wood mainly as a means of protection, and not also as a source of food as does the Shipworm.

There are a number of Crustaceans which habitually bore into wood. One of these stands out pre-eminent, like the Shipworm amongst the Molluscan borers, on account of its ubiquity and the great damage that it does. It is the Gribble, *Limnoria lignorum*, a little creature resembling a miniature woodlouse, usually between one eighth and one sixth of an inch long and with a semi-cylindrical body divided into segments (Plate 52). It has seven pairs of short legs each ending with a sharp, curved claw by means of which the animal holds on to the sides of the burrow. Beneath the hinder end of the body there are five pairs of legs each carrying two broad plates which act as gills, these keep up a continuous movement during the life of the animal and so constantly renew the water needed for respiration. The animal bores into the wood by means of a pair of stout "mandibles," one on either side of the mouth. These are not identical, for the one on the right has a sharp point and a roughened edge which fits into a groove with a rasp-like surface in the left mandible, the whole providing a "rasp-and-file" combination, as shown in Figure 31.

Unlike the burrows of the Shipworm, those of the Gribble are always the same width throughout, so that it appears

as though the animals must come out of their burrows as they increase in size and start new ones. Another way in which the Gribble differs from the Shipworm is that it is always the fully-grown animals which start new burrows. To do this, they first of all hollow out a groove along the surface, keeping in the soft part of the grain, and then pass by a very easy incline into the wood. Usually the

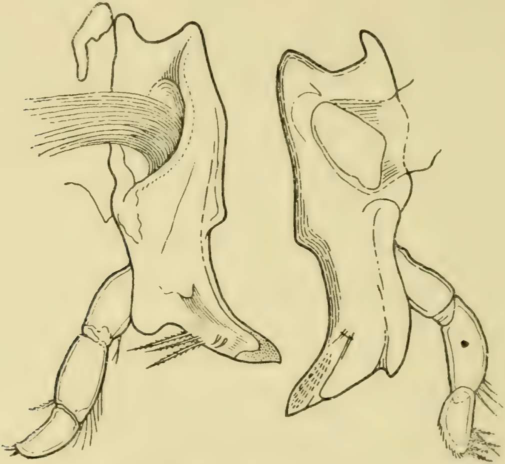
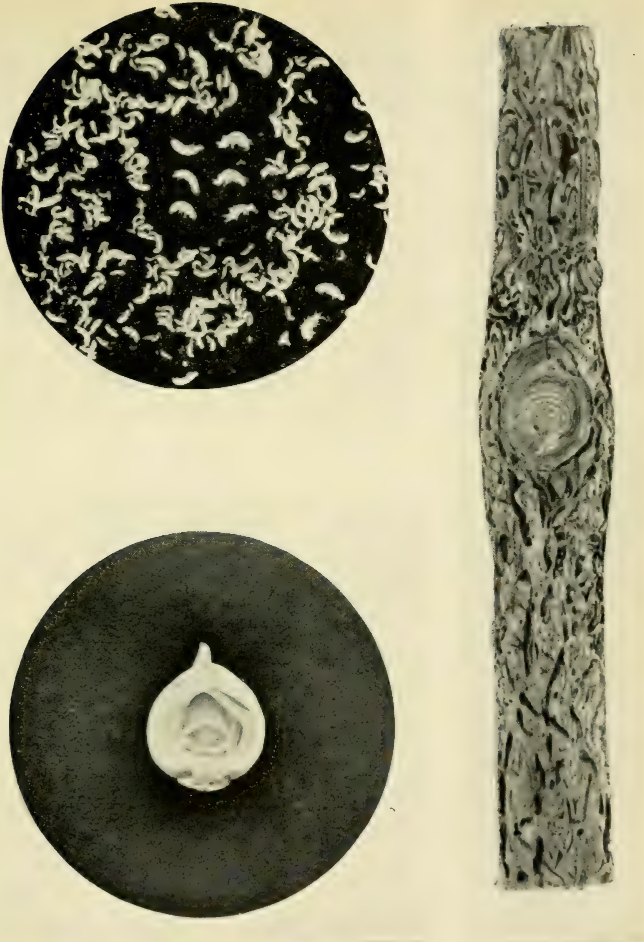


FIG. 31.—Mandibles of the Gribble, Limnoria, showing "rasp-and file" combination, greatly enlarged (after Hoek).

burrows are not deep ; the need for obtaining a constant supply of fresh sea water probably controls this, and, though they have been found as deep as three-fifths of an inch below the surface, they do not usually penetrate for more than a third of this distance. The burrows are often three-quarters of an inch or more in length. It is easy to follow the course of a burrow from above be-



Pl. 52. K 144.

Left: above, **Boring crustacea,** *Limnoria* (slightly enlarged).
below, **Boring mollusc,** *Xylophaga.* ,, ,,
Right: **Wood bored by** *Limnoria;* notice how the hard knot has not been bored. Natural size. (pp. 142, 143, 146).

Pl. 53. K 145.

Wood bored by Shipworm (*Teredo norvegica*). $\times\frac{1}{2}$. (p. 142).

cause the roof is perforated by a regular series of fine holes (Fig. 32) like minute "man-holes" which probably help the animals within to maintain the necessary circulation of water within the burrow. The female appears to do most of the work, for, though there are usually a pair of Gribbles in each burrow, the female is invariably at the head end. When the males are touched they will crawl backwards slowly out of the burrow, but the females on similar provocation will brace themselves firmly against the side of the cavity by means of their broad tails and successfully resist attempts to pull them out. Probably

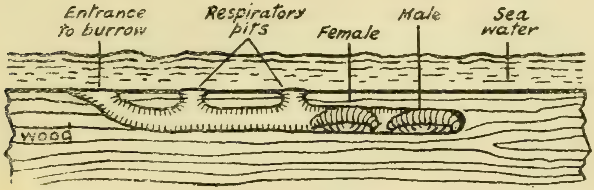


FIG. 32.—Diagram to show method of burrowing of the Gribble, Limnoria. Slightly enlarged.

they brace themselves in this manner when boring, for essentially the same purpose as the Shipworm uses his sucker-like foot.

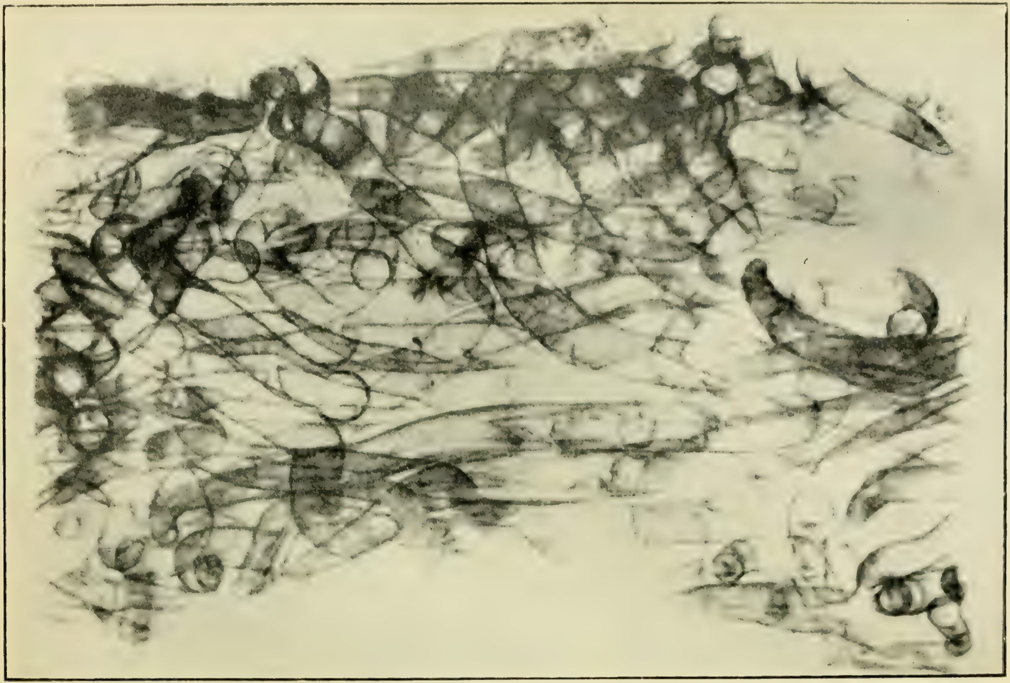
Instead of the myriads of minute eggs which the Shipworm discharges, the female Gribble only produces about twenty or thirty eggs but she takes very good care of these and incubates them in a special "brood-pouch" beneath her body. There the developing Gribbles remain till they have reached a relatively large size and when they finally hatch out they are about one-fifth the size of their parents and are fully formed animals capable of proceeding immediately about their life's business of boring. They

do this by hollowing out little burrows from the side of the parent burrow, and *never* by leaving the burrow and beginning a new one in fresh timber. As we shall see later, the fact that fresh timber is always infected by adult and not young Gribbles is unfortunate from the point of view of the protection of wood.

The ravages of the Gribble are always clearly apparent on the surface of the wood which is gradually rotted away until the outer layer falls off; the Gribble is then able to penetrate still deeper and so, layer on layer, the wood is destroyed (Plate 52). The Gribble is always especially abundant in such structures as pier piles about low-water mark and here it eats deepest into the wood, which tapers away and finally breaks through at this point. So numerous are they in badly infected wood, that between 300 and 400 Gribbles have been collected from a square inch of timber.

There is no evidence that the Gribble can actually digest the wood though it certainly swallows large quantities of the fragments which are bitten off by its powerful mandibles. It has been found boring in the insulating covering of submarine cables so that clearly it does not depend on wood to the same extent as does the Shipworm which has never been found anywhere but in wood. Some of the other crustacean borers and the mollusc Xylophaga have also been found in the insulation of cables and all these creatures appear to bore for the protection it affords them and not for the purpose of obtaining food.

There are several other crustacean wood borers. The most common of these is a creature known as *Chelura terebrans* (it has no common name, unfortunately) which is slightly larger than the Gribble, and flattened from side to side, being a relative of the common sand-hoppers of the shore. It usually works along with the Gribble, but nearer the surface of the wood, and is almost as world-



Pl. 54. K 146.

X-ray Photograph showing borings of Shipworm (*Teredo*) in wood. (p. 141).

Pl. 55. *p.* 147.

Boring Molluscs and Sponge. $\times \frac{1}{2}$.

Top: Left, *Saxicava rugosa*; centre, **Oyster bored by Sponge,** *Clione.* Right, **the Piddock** *(Pholas dactylus).* Bottom: **Red Sandstone bored by various kinds of Piddock,**

(pp. 147, 148, 149).

wide in its distribution. Since it is rarely, if ever, found apart from the Gribble it seems as though it needs the pioneer assistance of that highly competent animal before it can itself attack the wood with any success. In the warmer seas in particular there is a common crustacean borer called Sphæroma which is rather like a large Gribble, to which it is fairly closely related. It often measures almost half an inch in length and constructs burrows about a fifth of an inch wide. It has the habit, when disturbed, of rolling itself up into a round ball. It does not do so much damage as the other two crustaceans but can work, as they cannot, in water that is almost, or entirely, fresh.

Stone Borers

In spite of its greater hardness, stone is bored into by a greater variety of animals than is wood, although none of the stone borers can compare with the Shipworm in efficiency. Amongst the animals which bore into stone are Sponges, Worms, Molluscs, and Crustaceans, while it is also attacked, strange though it may sound, by plants. Limestone rock and especially oyster shells (made of the same calcareous material) are often eaten into by a boring sponge called Clione (Plate 55). The surface of the rock or shell is found covered with many minute holes which lead into branching passages within which the sponge lives. Oyster shells may be completely destroyed in this manner and on some oyster beds the boring sponge is a serious pest ; it seldom penetrates far into rock, two inches at the most. How the sponge bores is not known, probably by chemical means for it can hardly do so mechanically.

Several worms spend their lives within tubes which they have hollowed out in rock. Though very small they often occur in great numbers. The tubes are often U-shaped but may be oval or in the form of a figure of 8. Though

these worms all possess horny bristles which may assist them in burrowing, it is probable that the greater part of this work is done by chemical means.

But, as in the case of the wood borers, the largest and most efficient rock borers are bivalve Molluscs. Of these the largest is the familiar "Piddock" (Plate 55) which is a stout bivalve with a white, spiny shell sometimes as much as six inches long. It is distantly related to the Shipworm and more nearly to the other wood-boring Molluscs. It bores by the rasping action of its shell, the rows of spines with which this is furnished gradually cutting into the rock until a burrow of anything up to one foot in length, in the largest specimens, is constructed. The Piddock is indifferent as to the nature of the stone into which it bores, it has been found in limestone, sandstone, shale, mica-schist, peat and, very occasionally, wood. In specimens which bore into soft material the spines are long and pointed, in those taken from harder rock they are round and blunt. During the operation of boring, the head of the burrow is held by the sucker-shaped foot, as in the Shipworm, while the shell twists and rocks on this fulcrum. There are limits, apparently, to the efficiency of this apparatus because the Piddock is never found boring in the very hardest type of rocks. Moreover, though the head of the burrow is certainly hollowed out by the mechanical action of the shell, the hind end of the burrow also increases in width as the animal grows so that it appears that there must be some kind of chemical action for only the soft, fleshy siphons are in contact with the rock in this region. A peculiar feature of the Piddock is the fact that, though it lives hidden away in rock, it is luminescent (see Chapter VIII).

There are a number of different species of Piddocks, all belonging to the genera Pholas, Barnea and Pholadidea, which are very common, while there are a number of rather

rarer rock-boring molluscs of which perhaps the most interesting is *Petricola pholadiformis* which, though it belongs to a family of bivalves far removed from the Piddocks, has come, as a result of its similar habit of life, to resemble these animals to a striking extent. The commonest of all rock borers is a smaller mollusc, never more than about one inch long, called Saxicava (Plate 55) which is everywhere abundant both in deep and in shallow waters. Usually it is found in limestone rocks, often in those of such hardness that it seems impossible that so comparatively delicate a shell can have excavated the burrows. It is probable that at least a certain amount of the boring is performed by chemical means, although this animal is also found in rocks, such as sandstone, where chemical action would be unavailing. No especial glands for the production of acids for eating away the rock have been discovered in either Saxicava or the Piddocks but it may be that the soft parts of the body which project beyond the shell may exercise a solvent action of some kind.

There is one rock borer which undoubtedly makes its burrows by the aid of chemicals. This is the Date-mussel of the Mediterranean and tropical seas, so called because of its resemblance in colour, size and shape, to the date. It is a close relative of the common mussel. The brown, date-like colour of this animal is due to the presence of a thick horny layer over the surface of the shell, which is itself very fragile and devoid of teeth or spines. It always burrows in limestone or some other calcareous rock (Plate 56), not by the action of the delicate shell but by the aid of an acid which is produced by a special gland in the soft tissues just within the shell. Acid attacks calcareous matter very readily but not other forms of rock and this is the explanation of the invariable preference of the Date-mussel for calcareous rocks. The shell, of course, is also

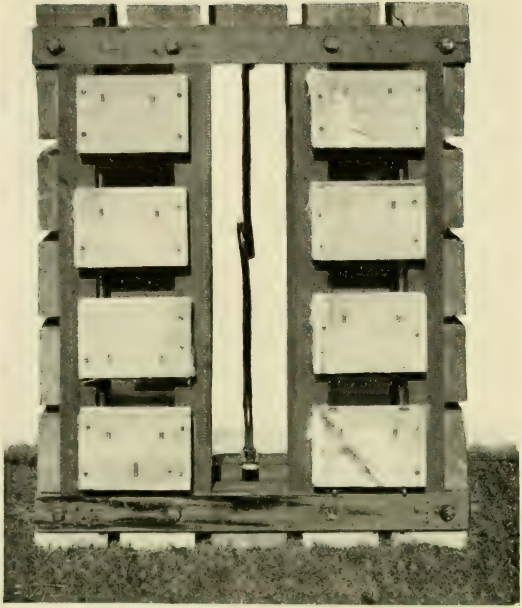
made of calcareous matter but this is protected from the action of the acid, as we have seen, by the covering of horny matter. The acid-producing gland is not present in closely related mussels which do not bore into rock. The borings of the Date-mussel have proved of great value in a somewhat unexpected connection, that of earth movements. The classic example is the borings in the limestone pillars of the Temple of Seraphis at Pozzuoli near Naples. These pillars are to-day some distance above sea level, but for some distance upwards are perforated with the burrows of the Date-mussel. Since the temple must originally have been built above sea level, it is clear that the land sank until the pillars were covered at least to the extent to which they have been burrowed into. It is just as obvious that since that time the land has risen again so that the temple is once more on dry land. Thus the presence of the holes made by the Date-mussel enables us to prove that the land in the neighbourhood of Pozzuoli has both sunk and risen again within historic time.

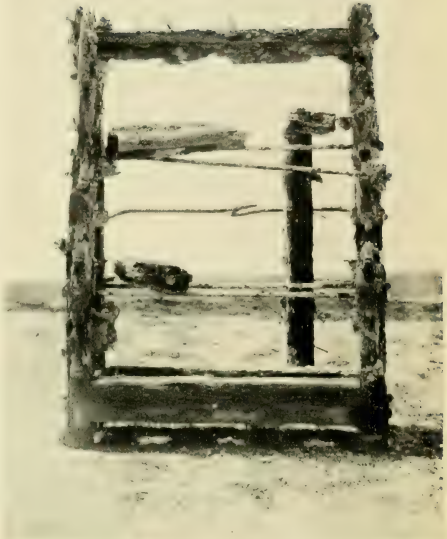
Crustaceans do far less damage to stone than to wood. Both limestone and coral are bored into to a slight extent by certain barnacles, but the only Crustacean which does much damage is another species of the Sphæroma which bores in wood. This creature can only work in soft sandstone or claystone but has done considerable damage in New Zealand by destroying harbour works made of the latter material.

The rock-boring animals cannot obtain any food from the rock; they make their burrows and live in them purely on account of the shelter with which they are provided. The borrows are never long and the animals are in free communication with the water outside and from which they take their food which in all cases consists of fine particles or microscopic animals and plants. In general,

Pl. 56. *L* 150.

Date Mussels *(Lithophagus lithophagus)* **boring in rock,** × ⅔. (p. 149).





Pl. 57. *L* 151.

Destruction of Wood by Shipworm. (p. 154).

Raft before putting in sea. A raft after about 3 years in sea.

therefore, they resemble all the wood borers with the exception of the remarkably specialized Shipworm which is unique amongst borers in its inability to make a new burrow if removed from the one it originally constructed, and its capacity to extract nourishment from the substance into which it bores.

Besides being attacked by animals, rocks, surprisingly enough, are also bored into by sea weeds. Here again it is only limestone or other calcareous rocks which are attacked, and the plants appear to prefer the harder varieties which, by their action, are soon reduced to a friable mass coloured blue or greenish owing to the weed everywhere present in its substance. Their preference for calcareous rocks is due to the fact that, like the Date-mussel, they bore by chemical means, transforming the hard carbonate of lime which composes the rock into the soft, powdery, white bicarbonate. Besides rocks they attack the shells of molluscs, doing great damage to the oyster beds in the Bay of Sebastopol in the Black Sea where they are especially common. They attack in the same regions the shells of barnacles, the calcareous tubes of worms and the external limy skeletons of other marine creatures all of which are coloured by their presence. Their prevalence in the Black Sea, where they are common in all depths down to about 75 feet, is a serious economic problem on account of the damage they do both to stone work and animal life.

Protection of Timber

The problem of the protection of timber from the attacks of marine borers has vexed mankind since the days of the earliest wooden ships and harbour works. To-day, though the advent of steel ships and concrete harbour works has led to a great reduction in the use of timber in marine

structures, the problem still remains unsolved. How urgent the need for a solution is, can be judged by the extent of the damage done in San Francisco as the result of a great burst of activity by the Shipworm in that district between 1914 and 1920, when wooden piers and wharves to the estimated value of ten million dollars were destroyed.

Innumerable remedies and protective measures have been tried with varying degrees of, but never complete, success. Different woods vary with regard to the speed with which they are attacked. Hard woods, such as teak or oak, are attacked just as quickly as softer woods, but some woods resist attack for a longer period owing to the presence in them of essential oils or poisonous alkaloids. Greenheart and Eucalyptus are examples. One of the methods of protecting timber consists of leaving the bark intact, for this often contains such protective oils. The wood, however, requires very careful handling or the bark is injured and the wood borers make their way through the damaged places. In any case there is always the danger that the animals will enter about the knots in the wood.

It is impossible here to do more than give a list of a few of the more important methods of protecting timber. Protective measures fall naturally into two main divisions, those which protect the surface of the wood and those which impregnate it with poison. Piles have been painted with a great variety of substances in the hope of keeping out borers, amongst them may be mentioned tar, copper paints, and innumerable patent preparations. These are usually efficacious while the coating remains intact which, in the case of pier piles which are continually being scraped by the sides of ships, is not long. Charring or " breaming " of timber is another old method of protection, but is not, apparently, very effective. Then there are a large number

of methods which aim at the protection of timber by armour of one kind or another. Metal has been largely used for this, steel or iron sheathing has been employed but found to corrode too quickly, zinc and Muntz metal (an alloy of copper and zinc) also giving indifferent results ; much better are casings of cast iron or copper. The latter is highly poisonous to all forms of life but is expensive and, unfortunately, much sought after by thieves. Vitrified pipe castings have been found to give excellent protection but they, in their turn, suffer from the serious defect that they are easily broken. A great number of patent armours of one kind and another have been put on the market but, though they give initial protection, all break down sooner or later and the wood borers enter. Concrete casings are largely used at the present day, especially in the United States, and they are often very effective but there is always the danger that the concrete will be attacked chemically by the sea water or that it will break away near the base of the pile and so allow borers to effect an entrance there and work their way upwards. An old and very effective method consists of covering the surface of the wood with broad-headed iron nails, known as "scupper-nailing." The rust from the nails spreads and forms a complete coating over the surface and with satisfactory effect. All these methods are more effective with the Crustacean borers than with the Shipworm, since the former can do little damage unless a good deal of the surface is exposed whereas a very small unprotected area will allow comparatively large numbers of minute larval Shipworms to begin boring, and these may each penetrate into the wood for a depth of a foot or more, according to the particular species.

The best method of protecting timber against the ravages of the Shipworm is to impregnate it with some poisonous

substance. Scientific investigations into the most suitable means of affording this type of protection have been conducted both in this country and in the United States for some years past, by the Sea Action Committee of the Institution of Civil Engineers in the former and by a Committee on Marine Piling Investigations in the latter. After exhaustive tests of a great variety of substances, various organic compounds containing arsenic, some of which were used as poison gases during the war, have been found the most efficacious, and important experiments are now being carried out with these substances, by exposing in the sea rafts containing timber treated in various ways, and finding the degrees of protection afforded by the various poisons (Plate 57). In all cases it is necessary to impregnate them into the wood in solution in creosote, otherwise they wash out and the wood is left fully exposed to infection. The creosote alone, if the timber is well impregnated with it, often provides good protection for a long period. The wood has to be thoroughly dried before impregnation, the latter process being carried out either by the aid of a vacuum which draws the creosote through or else by boiling with the impregnating fluid in an open tank. Up to date these experiments are having good results so far as the Shipworm is concerned but are not so efficacious with the Gribble, which appears to be less susceptible to poisons. This is probably to be explained by the fact that only fully grown Gribbles attack new timber and these will not be so easily poisoned as the minute larval creatures which are the carriers of infection in the case of the Shipworm. The age-old problem of the protection of timber in the sea remains, though progress is slowly being made, still unsolved.

The rock borers do not do a fraction of the damage of the wood borers and are a minor problem. Mechanical borers, such as the Piddock, may do a good deal of damage

to soft rocks, and calcareous rocks are always in danger from the chemical borers, like the Date-mussel, but if these types of rock are avoided there is no danger. Moreover they work much slower and penetrate far less deeply than do the wood borers Cement and concrete are seldom attacked by them, though there are a few recorded cases of these substances being bored into by Piddocks or their relatives.

CHAPTER VII

Coral Reefs

In the last chapter we learnt something of those animals and plants which are the chief agents of destruction in the sea, in this chapter we are going to deal with animals and plants which, so far from being destructive, are responsible for the formation of many thousands of islands and reefs in the tropical seas. Everyone has heard of coral reefs and probably seen pictures of them, but few, perhaps, have had their imaginations roused by the thought of the amazing manner of their formation. For it is surely a very remarkable thing that animals allied to our common sea anemones, and plants related to the little red corallines, have between them built up—by the slow but persistent process of converting the calcium salts in solution in the sea water into hard calcareous rock—dry land where there was before open sea, land on which first of all plants, then animals and finally men, have successfully established themselves.

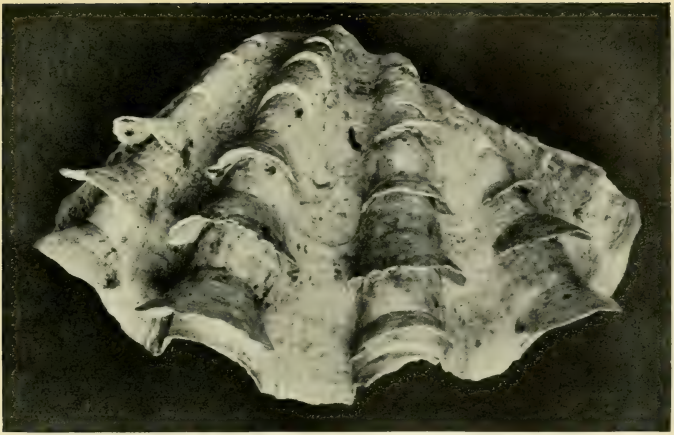
Before we go on to speak of the various kinds of coral reefs and islands and of the different theories which have been put forward to account for their formation, we must first say something about the animals and plants which are responsible for their formation. The most important of these are the stony or Madreporarian corals which, as was briefly alluded to in Chapter I, are animals of the sea anemone type which form around and beneath themselves a thick protecting skeleton of carbonate of lime. Although some of these are "solitary" corals like the little cup-coral,

Caryophyllia, of our own seas, i.e., like anemones but with a surrounding skeleton, the majority of the reef building varieties are of the "colonial" type. They form great colonies consisting of large numbers of individuals, the skeletons of which are all fused together to produce a great stony mass. The bleached corals we see in our museums or such as are shown in Plates 58 and 59, are really only these empty calcareous skeletons, which in life are covered with the delicately coloured tissue of the coral itself, while under water the beautiful feeding polyps, each surrounded by a ring of tentacles, open and expand. The openings from which these polyps project can easily be distinguished in the coral skeleton, and will be found to lead not into a smooth rounded opening, such as one can imagine an anemone occupying, but into a tube the sides of which are raised into a series of sharp ridges known as septa, and which penetrate almost to the middle of the opening. The presence of these septa is an important point of difference between the Madreporarian and the other types of corals, some of which we must now describe.

Although many scientists prefer to reserve the name reef-building coral to the "stony" Madreporarian corals, yet these, though the most important, are by no means the only organisms concerned with the formation of coral reefs. There are a number of corals allied to the little hydroids, from which they differ essentially only in the possession of a thick calcareous skeleton forming at least four-fifths of the entire mass, through fine apertures in which project the tiny polyps which are all united to a common canal within. The commonest of these corals is one called Millepora, which is found in coral reefs all over the world. It has two kinds of polyps which have a perfectly definite arrangement. If a piece of the whitened stony skeleton of this coral be examined it will be found to be covered with a series

of fine apertures each consisting of a central opening surrounded by a ring of from five to seven smaller ones. The former is occupied in life by a relatively stout, stumpy polyp, which has a mouth and a digestive cavity, while through the smaller ones project long, slender structures, each with a series of little tentacles branching from the main axis. These are all without mouths, but have batteries of the stinging cells with which such animals paralyse the minute animals on which they feed. These stinging cells are so powerful that they can penetrate human skin causing a painful nettle-rash, so that Millepora is known as the Stinging Coral. Apparently the two types of polyps work in conjunction, the one kind capturing the prey and then handing it over to the large central polyp, which swallows and digests it. As a result of continued branching, great masses of Millepora are formed while fresh colonies are begun by the attachment of the little embryos, which develop from eggs produced, not directly by the Millepora, but by very tiny swimming jellyfish, or medusæ, produced by the coral.

Some of the "false," or Alcyonarian, corals form important constituents of coral reefs. In this group is included the red coral of commerce which, as we shall discuss in more detail in Chapter XVI, is never found in coral reefs, being an inhabitant of temperate seas, and also the sea fans and the dead-men's-fingers of our own coasts. But other corals of this type are important constituents of coral reefs, one of which, as shown in Plate 59, having a remarkable type of growth, as a result of which the skeleton takes the form of a series of little tubes running parallel to one another and united by little platforms, an arrangement which has led to its being known to science as *Tubipora musica* and to the world at large as the Organ-pipe coral. The skeleton has a deep red colour, but this is obscured in life by the emerald



The Giant Clam *(Tridacna)*, $\times\frac{1}{3}$. (p. 166).

Pl. 58. *L* 158.

Stony Coral, $\times\frac{1}{2}$. (pp 157 162).

Right: *Fungia*. Left: another type of Stony Coral

Organ-pipe Coral *(Tubipora musica)*, $\times\frac{1}{2}$. (p. 158).

Pl. 59. *L* 159.

Stag's Horn Coral *(Madrepora)*, $\times\frac{1}{3}$. (p. 157).

green tentacles, which project from the free ends of the numerous little upright tubes. As a matter of fact, only the surface region of the coral contains living tissues, the skeleton below being abandoned as the colony grows, and becoming merely a supporting structure and, incidentally, the home of innumerable worms, crabs, sponges, seaweeds and many other forms of life. Unlike the stony corals and Millepora, the skeleton of this coral is not solid, but is composed of many tiny calcareous spicules all fused together. Exactly similar spicules are found in our own dead-men's fingers, but there they are scattered about in a matrix of spongy tissue. Another interesting coral of this type is the Blue coral, Heliopora, which forms massive colonies often several feet across; if the branches are cut through, however, the skeleton is seen to be composed of many parallel tubes like the Organ-pipe coral. The skeleton of the Blue coral is remarkable in that it is composed, not of fused spicules, but of a solid mass of crystalline carbonate of lime.

Besides the floating Foraminifera, so common in the surface waters of the oceans, there are others which live on the bottom and form irregularly branching skeletons, and these, together with the empty shells of the floating kinds, form an important constituent of coral reefs in many parts. But the chief factor in the formation of reefs, apart from the various types of corals—and in some areas of equal or even greater importance—are the calcareous coralline sea weeds or Nullipores. Most of these belong to the red algæ, the most important of them being Lithothamnion (Plate 61), types of which, as we saw, frequently cover the sea bottom off our own coasts, Melobesia and Lithophyllum. They are all reddish in colour when alive, although the last-named turns white when dried. They are all very wide-spread, Lithothamnion, for example, occurring in great abundance in the Arctic Seas, off the British Isles, in the

Mediterranean and in the coral reefs of the tropics. They never form so thick a mass as do the true corals, being essentially encrusting plants forming a compact layer over any hard surface, rocks, stones or dead coral. An important green weed which also deposits carbonate of lime in its fronds and is so common as to form an important constituent of many coral reefs, is called Halimeda. It has a characteristic appearance being formed of a number of broadened, limy lobes united by narrow, uncalcified joints which make the plant relatively flexible.

Having indicated the chief agencies concerned in the formation of reefs, we must now turn our attention to their manner of growth and life in general, because, as we shall see later, these are of the very first importance in the formation of coral reefs. The great coral colonies develop by a process of budding and division from the original parent individual, in essentially the same manner as a plant sends out new shoots and branches, a method of increase which is known as vegetative propagation. Going back to the beginning of things, the young corals are incubated within the body of the parents for a little time, but at a comparatively early age the "larvæ" escape and swim about in the sea by means of a coating of fine hairs with which they are provided. At this stage they are minute, pear-shaped bodies no bigger than a pin's head. After a time they settle down on a convenient hard surface, the under surface spreads out to form a broad basal disc while the upper surface is pushed in to form a mouth and then a stomach cavity, while around the mouth grow out the tentacles.

The skeleton now begins to form and the individual grows to its full size encased both below and on all sides by a thick layer of carbonate of lime. If it is a solitary coral, it has now completed its development and has in

future only to maintain and reproduce itself, but if it is a colonial, reef-building coral it is only in the very earliest stages of its development. Division begins after the fashion shown in Figure 33, small individuals budding off from the side of the first-formed polyp. This may then continue to grow upward, increasing the height of the limy column, and budding off side polyps as it goes, the original polyp forming the apex of the whole colony. In another type of coral growth, the apical polyp, instead of being the original and oldest one, is the youngest, having been budded off from the polyp immediately beneath it and shortly to be superseded when it produces a bud in its turn. Many other corals have no specialized point of growth, all the polyps having equal powers of division and budding, and in these cases the colony spreads in a regular fashion over the surface of stones and underlying dead coral, finally forming a rounded mass such as that usually assumed by the important reef-building Porites. In some cases the division of the polyps may not be complete; instead of the surface of the colony being studded with many little round polyps, all quite distinct from one another, it may be covered with wandering, sinuous grooves all fringed with the characteristic septa and representing the site of polyps which have extended themselves as it were, budded off but never parted company with the

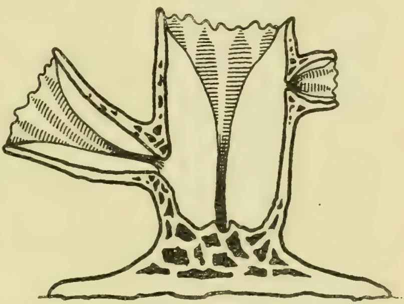
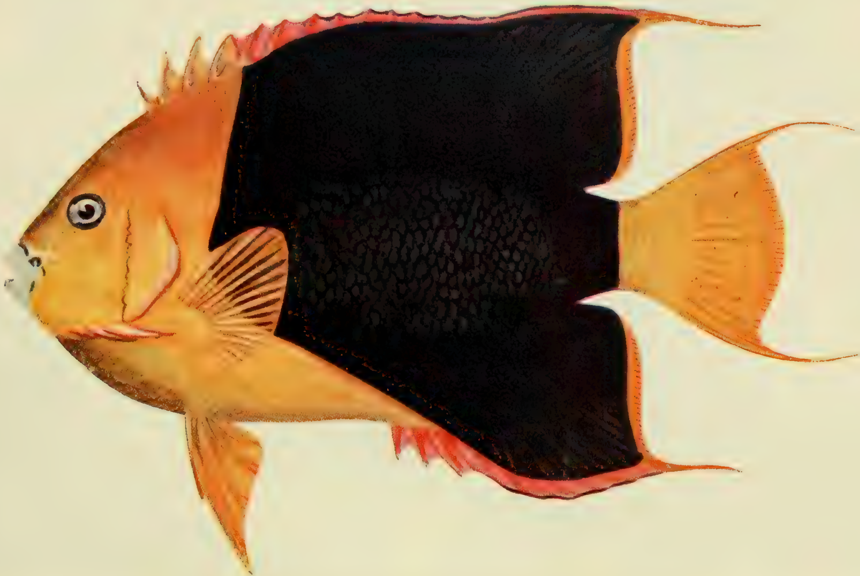


Fig. 33.—Diagram showing method of budding of Coral (after Wood-Jones).

bud. This type of coral is best exemplified by the well known Meandrina or Brain-coral, so called because the meandering depressions with which the surface is covered resemble very closely the convolutions on the surface of the human brain, as a result of which its surface, and so the all-important grey matter, is greatly increased.

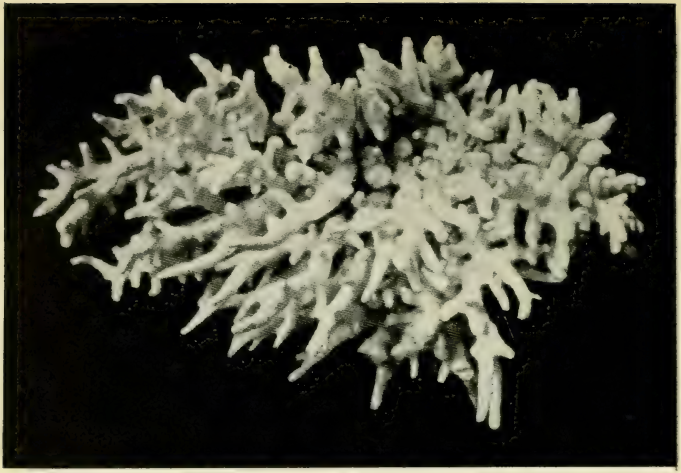
There is a remarkable solitary coral, common on reefs, which is worthy of a short description, so peculiar is its manner of development. The swimming embryo settles and develops into a little cup-shaped coral, but, on attaining a certain size, this swells out at the top until it looks almost exactly like a mushroom turned upside down so as to expose the gills (hence the name of the coral, Fungia). After a time this flattened upper portion falls off and drops on to the sand, where it continues to grow until it is often six inches across. The whitened skeletons of these stalkless discs, consisting of a circular disc with radiating septal plates (Plate 58), are common objects on coral shores and in zoological museums. The original polyp does not die when the flattened head falls away but starts again, as it were, and grows a new one which, falling off in its turn, is succeeded by an indefinite number of others.

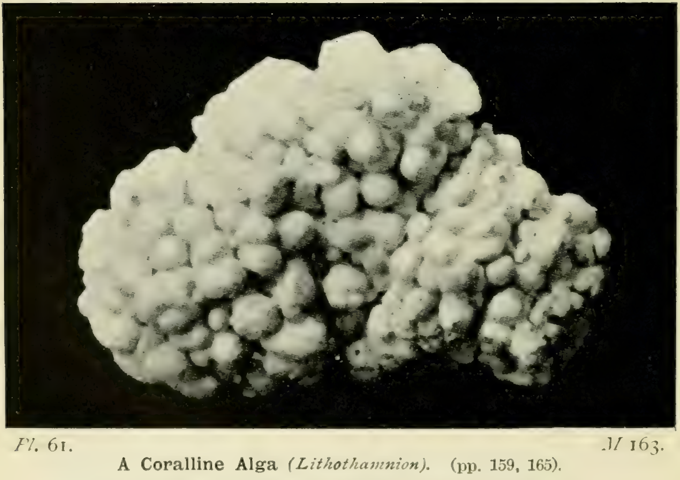
Corals grow like plants and they further resemble them in that the form the colony finally assumes depends very largely on the prevailing conditions. We know that plants grown from identical seeds will vary a very great deal if one is grown in a sheltered and otherwise favourable locality, while the other is in an unfavourable situation. A plant having a luxuriant growth in the valley may have a stunted growth and quite a different appearance when grown on a mountain top. In the case of corals, the chief factors influencing growth form are the depth at which they live, the degree of motion in the water, and the presence or absence of sediment in the water. The common Madrepora



Pl. 60. *p.* 162.

Coloured Coral Reef Fish *(Holacanthus tricolour)* with beak-like jaws, $\times \frac{5}{8}$. (p. 167).





Pl. 61. *M* 163.

A Coralline Alga *(Lithothamnion).* (pp. 159, 165).
Above, from calm water: Below, from rough water.

—probably the most widespread of reef-building corals—appears, for example, as a much branched, arborescent coral in smooth waters (Plate 65), as a single cylinder often of great length in deeper water, and as a solid, irregular mass in the rough water on the outer edge of the reef within the action of the perpetually pounding surf. The reason for these varied forms is to be found in the influence of these different conditions on the growth processes of the coral; in deep water which is always calm, there is nothing to prevent the original coral from developing on the "ideal" plan and growing straight upwards with a single apical point of growth from which polyps are budded off on all sides, but in the rather rougher conditions nearer the surface even in the most sheltered conditions, injury of the apical polyp leads to the establishment of new points of growth, each of which forms a new branch, while in the most exposed conditions perpetual injury of all projecting growths leads to the formation of a solid, irregular mass. At one time it was thought that these different types were all different kinds of corals, but now we know that there are relatively few kinds but unlimited variations in them all. The most striking example is that of the hydroid coral, Millepora, of which there are all manner of different forms but apparently only the one species in the world.

The effect of sediment is of the greatest importance. The coral polyps are able to expand and contract, and their exposed surfaces are usually covered with fine, rapidly moving hairs, the action of which helps to cleanse the surface, but these are their only means of protecting themselves from sediment and, like all attached animals, they are essentially at the mercy of material which drops on them from above or collects around them. A branching coral growth has less to fear from falling sediment than a massive growth which offers a wide surface on which it can collect.

The effect of this is finally to kill, by a kind of suffocation, the polyps in the centre ; growth consequently ceases in this region but is continued round the edges where the polyps are uninjured, the sediment having slipped off. and so the coral changes from a globular mass into a great, shallow cup. Another way in which sediment may affect corals is by accumulating around their bases and killing the lowermost polyps.

Of the greatest significance in the study of coral reefs are the feeding habits of corals. We should naturally expect that, being so like anemones, they would feed in the same manner, seizing living or dead animals by means of their tentacles armed with batteries of stinging cells, and later digesting them in the stomach cavity. We do find this type of feeding exclusively in some corals and to some extent in practically all, but they have added to this another mode of feeding in which they rely on the assistance of plants. This strange association between animals and plants is called symbiosis, and is explained in more detail in Chapter IX. In the majority of corals, of all types, the stomach cavity and also the tissues, especially around the mouth and tentacles, contain great numbers of minute, single-celled plants or algæ. So numerous are they that in some kinds of corals they practically obliterate the stomach cavity and in one most striking instance this cavity is completely shut off and left without an opening to the exterior, so that food cannot be swallowed in the normal manner. Often they are so numerous as to give a green colour to the coral. Like all plants they feed by taking carbonic acid gas and various salts from solution in the sea, for which purpose they must have light, a fact of the greatest importance in the distribution of corals, for all those dependent on the plants *must* live in water shallow enough for the latter to obtain the necessary degree of illu-

mination. The corals found in deep water, significantly enough, *never* have these associated plants. It appears that in many cases the corals are not absolutely dependent on the plants, for if there is animal food to be obtained—and this will usually consist of members of the minute drifting life of the sea—this will be seized and swallowed and the plants left unmolested in their sheltered home where they grow and increase by dividing. But should there be any shortage of animal food, the corals fall back on the plants, which are brought into the stomach cavity and there digested. In the cases where the stomach is cut off entirely from the outside, the coral must depend absolutely on the plants.

It is difficult to estimate the growth of corals, for this depends so much on conditions, especially temperature and the supply of food, but it has been found that the branches of Madrepora may increase by one or two inches in length per annum, while a mass of Porites increased its diameter by thirty inches in twenty-three years. Other estimations have shown that a shallow-water reef might, under favourable conditions, grow upwards at a rate of about one foot in eleven and a half years, or fourteen and a half fathoms in one thousand years. In Samoa, Dr. Mayer came to the conclusion that the corals added some 840,000 pounds of limestone to the reef annually, although about four times this amount is removed in the same period by currents, sea cucumbers and other coral-eating animals. This is not the only evidence we possess which indicates that coral reefs, in some areas at any rate, may, at the present day, be decreasing rather than increasing.

The Nullipores or calcareous seaweeds grow as sheets (Plate 61), usually comparatively thin, though masses two feet thick have been reported from the Indian Ocean. They vary in abundance from place to place, being clearly of first-rate importance in some areas, such as the Maldive and

Laccadive Islands off the south of India, and of far less importance in others. Their chief rôle in reef formation probably consists of forming a kind of cement which binds together the masses of coral in the cracks of which collects sand, formed by the breaking up of the coral and from the tiny calcareous skeletons of the Foraminifera, all being covered over with a firm crust of calcareous weed. An important centre of rock formation is frequently provided by the giant clams, Tridacna (Plate 58), which live embedded in the coral mass, and have shells often more than a foot long and an inch or more in thickness.

Sooner or later the corals die, usually as a result of the accumulation of silt and debris, though sometimes the attacks of a filamentous seaweed and at other times exceptional freshening of sea water in enclosed areas, such as lagoons, cause the death of great numbers of corals. The corals are always bored into by a number of animals, notably the Date-mussel and species of Piddock (*Pholas*), described in the last chapter, and also by many kinds of worms and sponges, but their action, by causing the corals in response to strengthen their skeletons, is frequently helpful rather than the reverse. In the Red Sea and other coral regions there is a fish called Pseudoscarus, which appears actually to live on coral, its parrot-like beak biting off pieces which are later to be found in the stomach! These fish, together with the various boring animals, certainly assist very materially in the breaking up of coral masses after the animals which made them have died and the protective coating of living tissue thereby removed. In this manner (and also by the eroding action of the waves) a great part of the coral is broken up into sand and mud or dissolved in the sea water. Some animals play a very important part in this process whereby coral skeletons are returned eventually whence they came, in particular the large

sea cucumbers most of which live on the surface of the coral, where they swallow coral sand and fragments, reducing it to mud within their bodies, while one kind is said to burrow like an earthworm (whose habits and importance it so closely imitates) swallowing the coral rock and throwing up great casts of pulverised limestone. These animals are of many kinds, sizes and colours, attaining to lengths of over two feet and corresponding thicknesses. They are so numerous on the Great Barrier Reef of Australia as to provide the material for an important fishery, their dried bodies, known as *bêche-de-mer*, being exported to China, where they are esteemed as a delicacy. The importance of these, and similar, creatures in the conversion of coral limestone into sand and mud is great.

A reef of living coral (Plate 62) is literally a sea garden. The corals themselves are of all colours, many being brown with violet, pink or white polyps, others scarlet, green or yellow; the polyps of some corals are foliaceous with long tentacles while others are velvety masses with tentacles almost absent. And the other animals have colours just as vivid. There are many fish of the most varied and brilliant hues which dart hither and thither in little shoals amongst the trees of the coral forest, there are the many-coloured sea cucumbers, large tube-worms with brilliantly coloured crowns of tentacles, large sea anemones, innumerable crabs and all manner of other crustaceans, many of which live in definite association with the corals, a like variety of molluscs and all manner of encrusting organisms such as sea mats and sponges.

Reef-building corals can only flourish in shallow water within the tropical zone, being seldom in abundance below about thirty fathoms and needing a surface temperature of at least seventy degrees Fahrenheit, so that they are confined to a belt extending between thirty degrees north

and thirty degrees south of the equator. In this region they are to be found everywhere—except on the western shores of continents—that the necessary shallow water conditions prevail, and the coloured patches on the map shown in Plates 63 and 64 indicate how widespread are coral reefs and islands. The Great Barrier Reef of Australia, the greatest coral formation in the world, is 1,350 miles long, extending from New Guinea southward along the entire coast of Queensland.

Three types of coral reefs have been distinguished ever since they were investigated by the early navigators. *Fringing Reefs* develop around the shores of islands or continents and have no extensive or deep-water channel between them and the land. *Barrier Reefs* are also found off land masses, but at a much greater distance from them, so that there is a wide and relatively deep channel between them and the shore, through which ships can safely pass. Finally there are *Atolls*, which are not connected with land at all and consist of rings of coral, part of which is raised above the surface of the sea (Fig. 34). Within this ring is invariably a lagoon, the depth of which—like that which separates a barrier reef from the land—never exceeds fifty fathoms and is usually much less, and varies in size between a mere pool and an enclosed sea perhaps forty miles from side to side.

The formation of fringing and barrier reefs is clearly bound up with the structure of the land they border, to the constitution of which, however, they do not contribute, although, as the result of the raising of the land in past ages, dry land in many regions is composed of coral limestone, originally formed in the sea and now in some cases within mountains several thousands of feet above the level of the sea. The formation of the real " coral islands " or atolls is not associated with land, from which they may be separated by hundreds of miles, the land formed being purely of coral

origin. Nevertheless, the problems of coral reef formation are essentially the same in the case of both reefs and atolls and, as we shall see, there is reason for thinking that all kinds of coral formations may be brought about as a result of the same process.

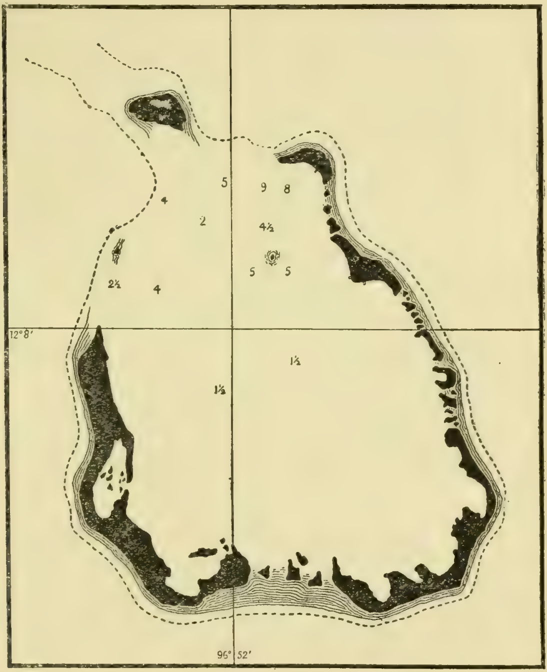


FIG. 34.—Chart of Cocos Atoll (after Wood-Jones).

An explanation of the formation of coral reefs is best begun by an examination of the means whereby fringing reefs are produced, about which there is no such mystery as

surrounds the formation of the other two types of reefs. Let us first assume the presence of a coastline, ideally situated for the growth of corals but which, perhaps because great earth movements have only recently raised it above the surface of the sea, has no growth of corals. Corals establish themselves in depths of thirty fathoms and less, and then proceed to grow upwards in the manner illustrated in Figure 35. When they reach low-water mark, upward growth ceases because corals cannot withstand exposure to the air for any but very short periods. Unable to continue upwards, the corals must grow outwards, and so

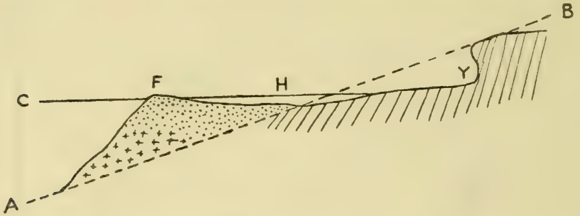


Fig. 35.—Diagram showing formation of a Fringing Reef; A-B, original slope of shore; C, level of sea; F, boulder zone at outer edge of reef; H, shallow passage between reef and land; Y, coast eaten into by waves; dotted area, Region of actual growing Coral; crosses, Region of dead Coral; shaded area, Land (adapted from Crossland).

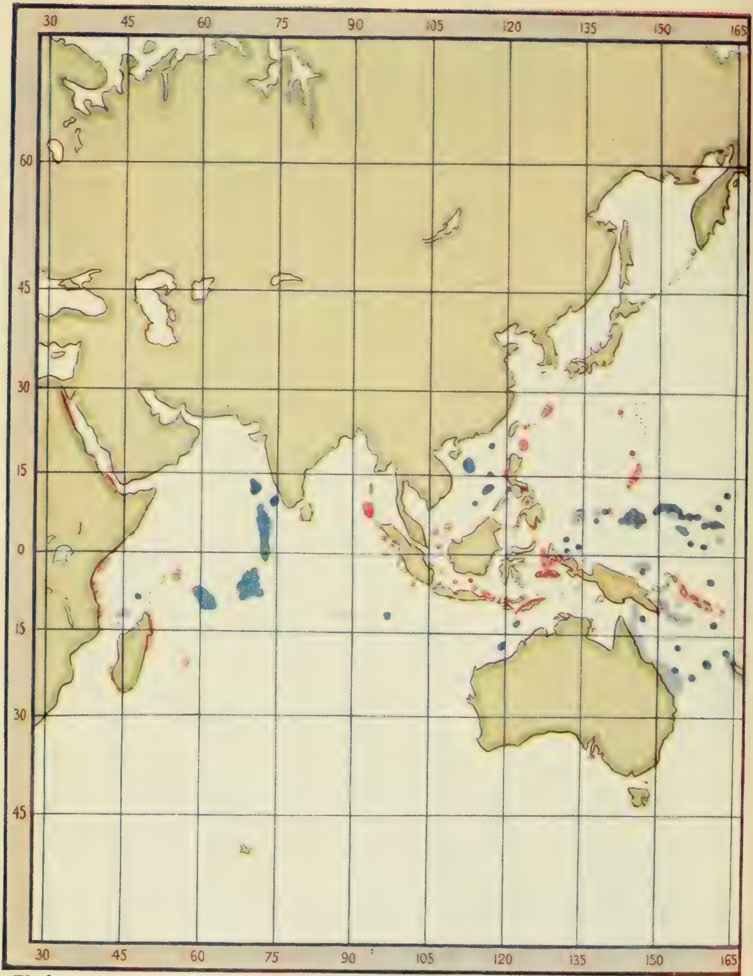
the coral mass becomes broader and also much steeper on its outer slope. The reason for this is that, though the corals near the surface could grow outward to an unlimited extent, they are actually limited by the growth of the underlying mass which can only extend outwards as far as the thirty fathom line, since below this line light is insufficient for the proper nutrition of their associated plants. Hence they stop growing while the mass above continues till a steep precipice is formed on the outer side of the reef, down the side of which fall coral boulders and debris of all kinds,

Photo. by W. Saville Kent.

Pl. 62.

M 170.

Part of the Great Barrier Reef of Australia. (pp. 167, 168).



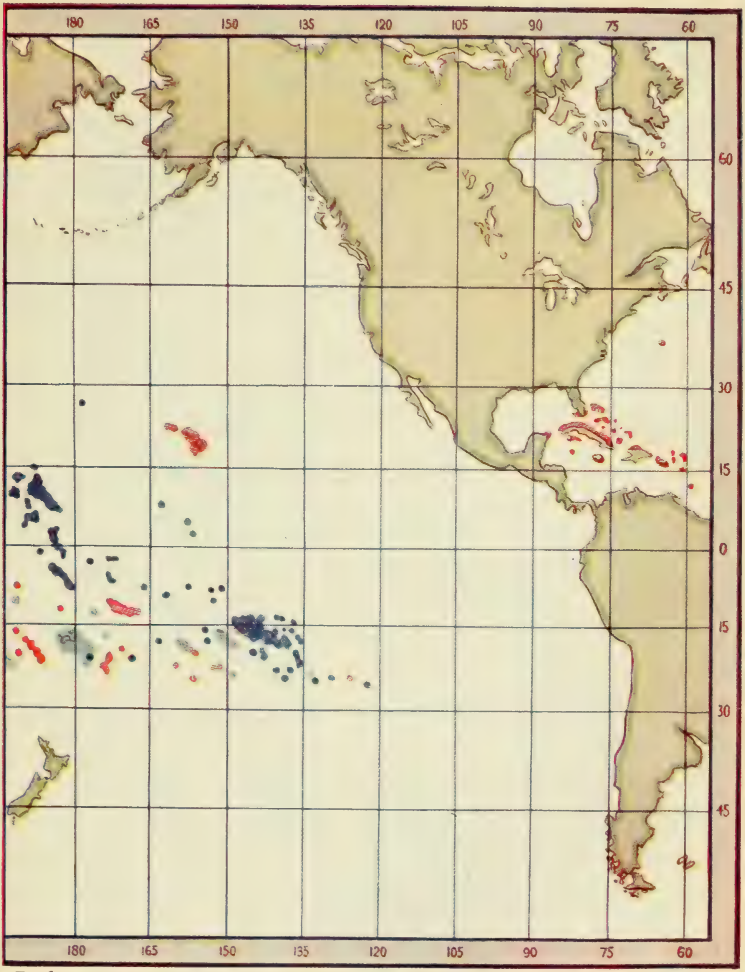
Pl. 63.

M.

Chart showing distribu

Dark Blue, Atolls: Light Blue,

The portion of the Atlantic Ocean



Pl. 64.

ʃ/

of Coral Reefs. (p. 168).
er Reefs: Red, Fringing Reefs.
own contains no coral formations.

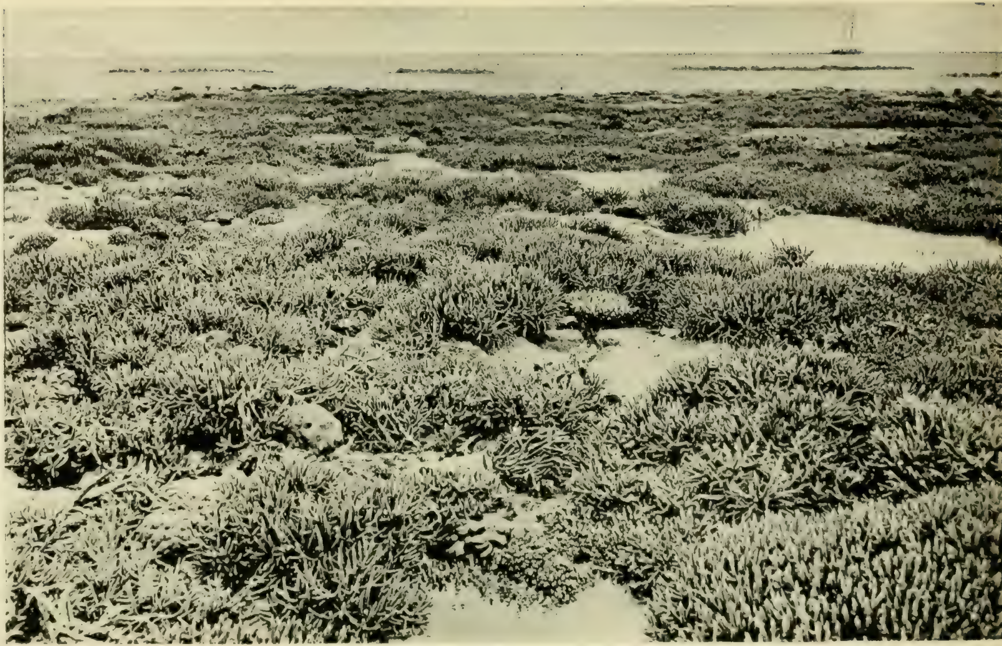


Photo. by W. Saville Kent.

Pl. 65. M 171.

Part of the Great Barrier Reef of Australia. (pp. 163, 168).

known as " talus," and this in the course of time forms a foundation for the further outward extension of the reef. The action of the sea, whose breakers unceasingly beat against the edge of the reef, causes portions of coral, shells and the like, to be thrown on to the " reef flat " as the flattened surface of the reef is called. As a result, the outer edge is marked by the presence of a long mound, known as the " boulder zone," which projects above the surface of the sea. The components of this boulder zone become cemented together and form solid rock, so that the reef will form a narrow strip of land fringing the land—hence its name.

The region immediately below water level on the outer edge of the reef is the area of most active coral growth. On the other nand, the reef flat between the boulder zone and the land becomes hollowed out to form a shallow, lagoon-like channel, sometimes deep enough for the passage of native boats. It is not known definitely exactly how these channels are produced, but probably the principal agencies at work are the scouring action of the sea as the waves rush over the surface of the reef flat, the action of the multitudinous boring bivalves, worms, sponges and so forth, and also, to a less degree, the direct dissolution of the limestone by the sea water. Occasionally, when an especially deep channel has been formed in this manner, living corals may be able to establish themselves once more in this region and, by their subsequent growth, fill up the channel. Finally, nearest the shore will be a second flat; very often formed of coral on its outer side only, the inner part being of land origin, having been formed by the sea which, at the end of its rush across the reef flat, has cut its way into the land.

This explanation of the formation of fringing reefs clearly cannot be applied to barrier reefs or atolls, the outer slopes

of which frequently descend to depths of hundreds and thousands of fathoms respectively. It is the mystery surrounding their mode of formation which has attracted the attention of zoologists and geologists since reefs were first accurately described, and has led to the development of a number of theories which attempt to explain the mystery. The most important of these are discussed below and, though no one of these has met with universal acceptance, yet all may contain elements of truth or apply to the formation of reefs in particular areas.

Theories of Reef Formation

The first, and most famous, theory concerning the origin of barrier reefs and atolls was put forward by the great Charles Darwin in 1842. He had observed, during his voyage round the world in H.M.S. *Beagle*, that reef-building corals can only exist in shallow water while, as a distinguished geologist, he also knew that the level of the earth may vary from time to time. By putting these two facts together he was able to elaborate a theory which, in its simplicity, bears the stamp of genius. He imagined a fringing reef developing, in the manner shown above, off land which was slowly sinking as a result of a general subsidence of the earth in that region. As the land sank, the corals would grow upwards and keep pace, more or less, with it, so that the outward edge of the reef about the boulder zone would maintain its position near or above the surface, but the shallow channel between it and the land would become deeper and deeper as the land sank and also broader as, bit by bit, the land was overrun by the sea. Finally, a typical barrier reef would be formed, often many miles from the new coastline, and with a channel up to fifty fathoms in depth. Here the matter would rest should some of the land remain above water—as in the case of Great

Barrier Reef and the coast of Queensland—but should the land have been a small island which finally sank, then all that would finally appear above the surface of the sea would be a ring of coral surrounding a central lagoon, in other words a typical atoll. This process will be made clearer by a study of Figure 36, which shows the various stages in the conversion of fringing reefs into atolls according to Darwin's theory.

At first this theory met with widespread support, notably from an American geologist named Dana, who studied many reefs, but as coral formations began to be studied in more detail and with ever increasing care, it was found that in many regions where corals flourished, so far from there

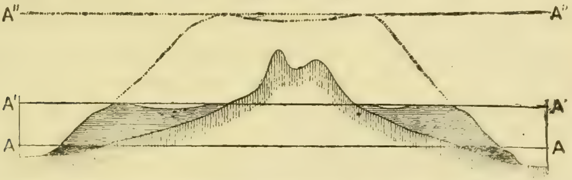


FIG. 36.—Diagram to illustrate formation of Atolls and Barrier Reefs by subsidence, according to Darwin's theory. A,A, Sea-level of island, with fringing reef in black; A',A', the same after some subsidence—island, with barrier-reef shaded; A'', A'', the same after the island has been submerged—atoll reef dotted.

being any evidence of subsidence of the land, there was definite evidence that the land was rising. Moreover, all three types of reefs are sometimes present in the same area, which is incompatible with Darwin's theory according to which the presence of a fringing reef is evidence that the land is stable while the presence of barrier reefs and atolls is evidence that it is sinking. Moreover, Darwin's theory demands that an immense belt of land between the tropics should have been steadily sinking over a long period of time, which would be certainly a very remarkable fact, if true.

Again there would have to have been great numbers of islands dotted about in the first place to provide the necessary basis for the countless atolls.

Sir John Murray, of whom we have already heard in connection with the investigation of the bottom deposits of the ocean, was the first to bring forward an alternative theory of any general application. The real crux of the problem is how to account for the presence of these platforms of land covered with not more than about thirty fathoms of water, from which alone, barring the subsidence of pre-existing land, corals could grow to the surface. Murray thought these were produced by a raising of the sea bottom. This might take place as a result of a submarine volcanic eruption throwing up a great mound of debris (these things do frequently happen, islands being occasionally thrown up above the surface of the sea in this way, the light material of which they are composed being usually washed away very quickly afterwards). It might also be brought about by the accumulation of great banks formed from the skeletons of the animals and plants of the floating life in the surface waters which are responsible for the greater part of the deposits on the bottom of the sea.

Now as soon as a platform is formed in this manner, reef building corals would be able to establish themselves and to begin growing upwards until they reached the surface, as shown in Figure 37. Clearly those in the centre, at the highest point, would reach the surface first and the preliminary indication of the beginning of an atoll, according to this theory, would be the appearance of a small circular reef flat. But the corals in the centre, being unable to grow upwards any further would die, while those on the fringes would grow outwards, extending the flat in all directions. Now, as in the case of the fringing reefs

(Fig. 35), the force of the sea would throw boulders of coral limestone on to the surface of the flat around the edge and here dry land would begin to be formed. Gradually the boundaries of the reef would be extended in all directions, more stones and boulders would be thrown up, some of which would be worn down by the action of the weather to form a soil in which seeds carried by the sea, or in floating timber washed ashore, or in soil attached to the feet of sea birds which alighted here, would establish themselves and grow. And so the beginnings of plant life would appear and, by the binding action of their roots, would establish the dry land yet more securely, while their decay after death would provide further, and richer, soil. Meanwhile the centre of the reef flat would become hollowed out to form a lagoon in essentially the same manner as the channel is formed between the fringing reef and the land. The water pouring in between the various islands forming the atoll ring (see Fig. 34), would scour and dissolve away (Murray laid great stress on the latter process) the dead coral in the centre and, with the aid of boring animals and plants gradually eat out a shallow lagoon. And so the process would go on, the atoll extending outwards like a " fairy ring " of fungus on grass, the broken fragments or talus falling down the steep slopes outside and furnishing a foundation for the further increase of the reef. In exactly the same

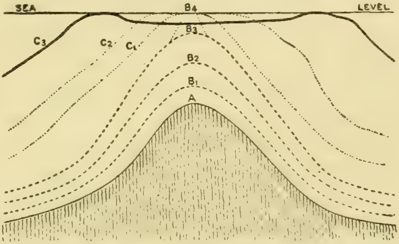


FIG. 37.—Diagram to illustrate the formation of an atoll according to Murray's theory. A, original mound on sea-bottom; B1-B4, increase in mound; C1-C3, outward extension of atoll by accumulation of talus falling down the side. Lagoon hollowed out by solution or eroding action of sea, etc.

manner, Murray thought that a fringing reef could be converted into a barrier reef.

This theory has many points in its favour, notably in that it does not demand any general subsidence of the land over the tropics. It has been supported by many more recent investigators of coral reefs, though often with qualifying statements and additions. The most important criticisms are concerned with the formation of the lagoon, for many scientists think that these are at present being filled up with sediment and not, as Murray's theory demands, gradually increasing by further erosion and solution, and that, in any case, they were originally formed by the scouring action of the sea and by the action of boring animals and plants, rather than by the dissolution on which Murray laid so much stress.

Clearly a definite proof of the origin of atolls might be hoped for if borings were made through the coral rock down into the lower layers. If the substance of the atoll was found to be of coral origin to great depths, then we should have strong evidence in favour of Darwin's theory, the coral limestone below about thirty fathoms being that which had been carried down by the subsidence of the land; if, on the other hand, a surface layer of coral limestone some thirty fathoms in thickness was found resting on a layer of solidified bottom deposits, of volcanic fragments, or similar material, then that would afford evidence that Murray's views are correct. With this end in view expeditions led by Professor Sollas of Oxford and Professor Sir Edgeworth David of Sydney, were sent out under the auspices of the British Association about the end of the last century. The object of these expeditions was to make borings through the atoll of Funafuti, one of the Ellice Islands in the middle of the Pacific. They succeeded after much hard work in boring through the atoll to a depth of

1,114 feet. The core of this bore was carefully preserved and brought to this country where it was examined from end to end by scientists in order to find out what it was composed of and, most important of all, whether it was formed throughout of coral limestone or whether that was succeeded by some different material in the lowest layers. This examination showed that the bore was composed throughout of the one substance, coral limestone, and this was at once claimed by the advocates of the Darwin theory as a vindication of their views. But now enters a complication for, without denying that the bore was composed throughout of rock of coral origin, Murray and his adherents stated that this was due to the fact that the bore, instead of going through the centre of the reef, had been made through the edge and so had passed through the talus of coral fragments which had broken off the edge of the growing reef and fallen into deep water.

And there the matter very largely rests. Probably both theories are correct for certain cases and there is no universally applicable explanation of the formation of coral reefs. The whole point, as we hope has been made perfectly clear, is the way in which the conditions—very clearly defined and well-known—necessary for the growth of corals are provided. Before we close this chapter, however, a short reference must be made to a more recent theory put forward by Professor Daly of Harvard, and which, whatever the amount of truth it contains, is of exceptional interest. Known as the "glacial-control" theory, this states that during the great ice ages so much water was locked away in the form of ice that the surface of the sea was lowered by between twenty-five and thirty-five fathoms in the tropics. During this period the pre-existing coral reefs (for coral reefs are known from the earliest times of which we have any geological evidence)

were destroyed but when the glacial period passed the water which returned to the sea gradually raised it to its former level and at the same time became warmed up, and in this warm water new coral colonies became established on the flat platforms into which those regions of the sea bottom exposed during the glacial period had been converted. As the water rose the corals growing on these platforms would grow upwards with it, in just the same manner as Darwin supposed, only in the former case it was the sea which was changing its level and in the latter the earth.

There is support for this ingenious theory from Dr. Mayer who calculated from the growth of corals in Samoa that the reefs in that region at any rate, could all have been formed since the last glacial epoch. On the other hand, we have no definite knowledge as to the amount of water which was taken from the sea during the ice age, while there is abundant evidence that many reefs are not founded on platforms which could have been formed in this way.

CHAPTER VIII

Colour and Phosphorescence

In this short chapter we shall consider two of the most interesting properties of marine animals, their colour and the strange power, which many of them possess, of producing light so that they appear phosphorescent at night. Though colour and phosphorescence are not directly connected they have this at least in common, that the production of the former is greatly influenced by light whereas the latter is concerned with the production of light.

Colour

In the sea there are animals with as great a wealth and variety of colour as any that are found on land. This is a fact which people who live in temperate climes are liable to overlook because our fishes have none of the brilliancy of colour of those from tropic waters, while the most beautiful of our marine creatures are anemones which often lie concealed in rock pools or contracted on the sides of rocks while the tide is out, or else small shrimps and sea slugs which are known only to the naturalist with the knowledge and enthusiasm to search for them.

The remarkable property of colour change—whereby an animal can change its colour to a greater or less extent, usually in order to tone with its background for the time being—is possessed by a far greater number of marine than terrestrial animals. It is especially well developed

in crustaceans, in the squid and cuttlefish family, and in fish. Amongst the first of these the most striking example, which has been thoroughly investigated by Professors Gamble and Keeble, is that of the little Æsop prawns (*Hippolyte*). These little creatures, never more than an inch in length, are very common on seaweed in rock pools and on rocky coasts but are very difficult to discover owing to the exactness with which they tone with the background.

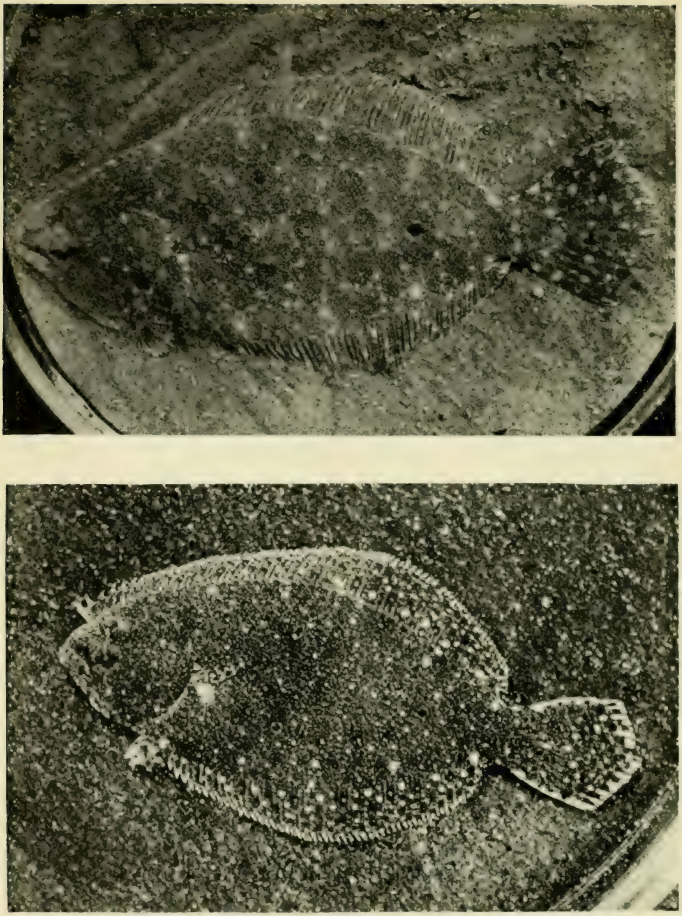
Beginning with the birth of the prawn; when the young hatch out they are colourless and almost transparent and drift about in the sea for some time, being finally carried inshore where, for the sake of the food and security afforded them, they cling to the first piece of seaweed they meet. They now begin to develop colour, a process which takes place quickly and always results in the animal assuming the exact shade of colour of the weed which it has chosen for its home. If this is a red weed from deeper water, the prawn becomes red, if a brown weed from the intertidal zone, it becomes brown, or if a green weed in the rock pools near high-water mark, it becomes green (Plate 66). The process begins gradually but at the end of a week the match in colour is usually perfect and the prawn almost impossible to detect.

If the Æsop prawn is driven from its home by unfavourable conditions, such as strong tides or currents, it searches for a new home of the same colour, but should this be impossible (as it may easily be made in the laboratory by placing collected prawns on weeds of different colour from themselves) then the prawn changes its colour to that of the new home and at the end of a week will have developed a new colour scheme just as exact an imitation of its surroundings as was the first. Quite independent of these enforced changes of colour due to change of sur-

Pl. 66. N 180.

Colour change in Æsop Prawn *(Hippolyte varians).* (pp. 180, 181).

Left: on brown sea weed. Middle: on green sea grass. Right: night colouration.



Pl. 67. *N* 181.

Colour Adaptation of flat-fish to different types of bottom. (p. 182).

Above, sand; below, gravel.

roundings are the nightly changes of colour which occur with unfailing regularity. Whatever colour the prawns may have by day, they *all* change to a beautiful transparent blue by night (Plate 66), the alteration in colour taking place quite quickly shortly after nightfall.

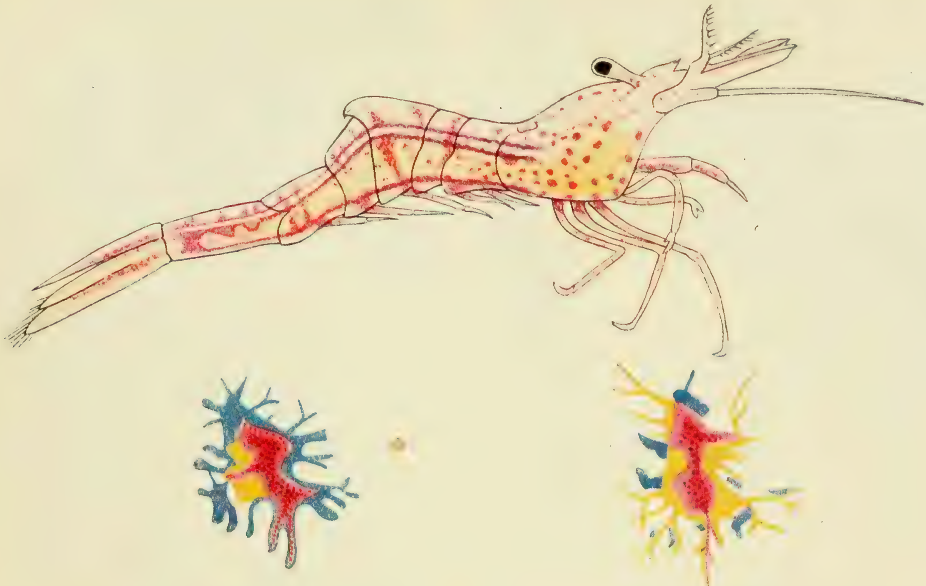
Great numbers of minute "pigment cells" scattered over the surface of the body are responsible for the colour of the Æsop prawn (Plate 68). Each of these cells consists of a central bag running out from which are many fine extensions. Within the central bag region there are three pigments, red, yellow, and blue, and the colour of the animal is controlled by the extent to which these pigments are spread through the branches, thus covering the maximum area, or withdrawn into the centre where they are reduced in area to a minute point and so hardly affect the general colour of the animal. The three colours may be associated in different ways; thus the red pigment alone occupies the branches when the animal is red, the green colour is produced when the red pigment is withdrawn into the central bag and the yellow and blue pigments together spread into the branches. The nocturnal blue colour is produced when the red and yellow pigments are both withdrawn and only the blue one extends into the branches of the pigment cells.

What is the mechanism which controls these remarkable and exact changes in colour? It appears that the pigment cells are influenced by the light which acts either by way of the eyes or directly on the pigment cells. Different coloured light affects the nerves controlling the flow of pigment in different ways, and ensures that the colour scheme produced shall tone with the background of the animal. The supreme importance of these elaborate mechanisms for colour change to these little animals is clear. There can be no doubt that the protection given

them by this cloak of invisibility is very great, and as they are not very active animals and enemies are numerous in the shore waters where they live, they possibly owe their survival to the fact that they are able to escape any but the most careful scrutiny.

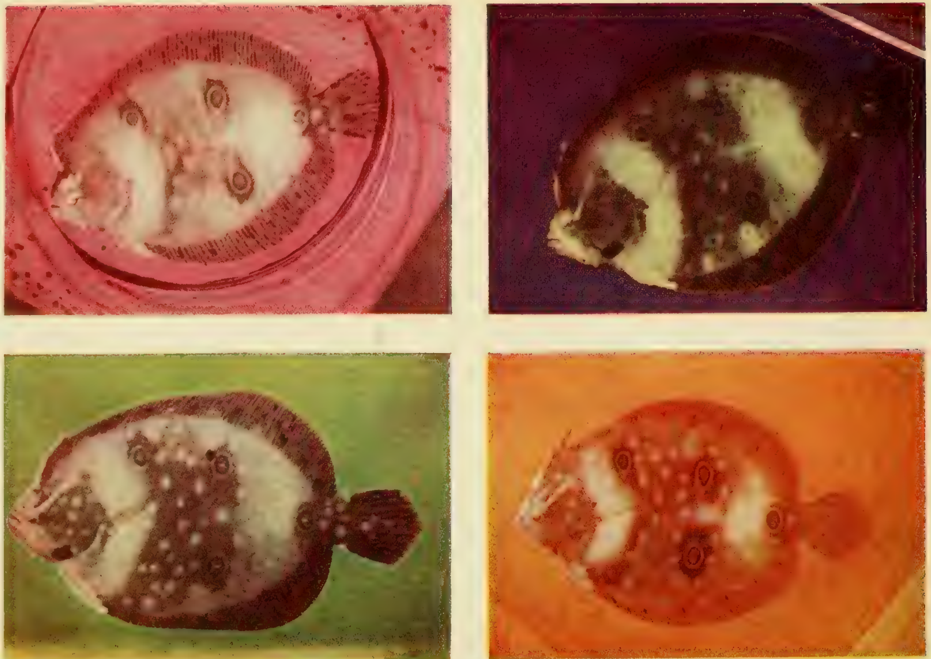
Anyone who has ever examined a living squid, or one that has only very recently died, cannot fail to have been impressed by the wonderful play of colour which sweeps over the torpedo-shaped body which blushes with delicate colour, and then as quickly blanches. In this case also the colour is controlled by tiny pigment cells, or "chromatophores," in the skin, but these are of quite a different nature from those of the Æsop prawn. Each one contains one colour only and this is not spread into branches or withdrawn according to whether or no it is needed, but instead the whole pigment cell is expanded or contracted by tiny muscles attached to the corners and in this way the area displaying that particular colour is increased or decreased (Plate 74). In this case the value of the colour change is far from obvious as the squids are swiftly moving animals which live near the surface of the sea with no darker background with which they might match their bodies. As in the allied cuttle-fish and octopus, changes of colour appear to be, in a sense, emotional, for the animals become suffused with colour at the sight of food.

Many fish have the power of colour change. Especially is this the case in the flat-fish, such as the sole, turbot, plaice or flounder, which live on the sea bottom and are liable to be attacked from above. If they are examined it will be seen that, whereas the under side of the body which lies on the bottom is unpigmented, the upper surface is mottled grey and brown so as to provide an almost perfect match with the background of mud, sand, or gravel (Plate 67). Here again pigment cells in the skin are responsible



Pl. 68. N 182.

Distribution of pigment cells in Æsop Prawn *(Hippolyte varians)*, **enlarged; and greatly enlarged cells showing different coloured pigments.** (p. 181).



Pl. 69. *N* 183

Colour change in American Topknot (*Ancylopsetta quadrocellata*), $\times \frac{1}{3}$.

Showing effects of different coloured backgrounds. (p. 183).

for the colour. These are of several varieties, some being black and others orange or yellow, while there are also bundles of crystalline needles which act as reflectors. The pigment cells can be increased or decreased, contracting to tiny points or sending out ramifying branches, and on the relative degree to which the different kinds are expanded or contracted depends the colour pattern of their owner. It is perfectly easy to experiment with flat-fish on different coloured backgrounds, and the accurate way with which the fish tone with them is shown in Plate 69. In this case light appears to be the deciding influence in colour change, though it never acts directly on the pigment cells. A blind fish is not able to change colour. The lack of pigment from the under side of the body is apparently due to the absence of illumination on this side under normal conditions, for if the fish are placed in glass bottomed tanks illuminated from beneath, they develop colour on the under, as well as the upper, surface.

Many marine animals are coloured in such a way as to blend with their surroundings, but do not possess the power of actually changing colour. This is especially true of many of the sea slugs, such as the common sea lemon, Doris, which lives on rocks and is yellow with mottlings of red and other colours, closely resembling the rock with its encrusting sponges, sea squirts, and red coralline seaweed ; an allied sea slug, the red *Doris flammea*, always lives on red sponges ; there is a small green sea slug named Elysia which always lives on green weed, and this list could be extended almost indefinitely. Many crustaceans are also difficult to detect in their natural surroundings and in this group, it may be remembered, there are many instances of "masking," the animals draping themselves in seaweed, sponge, or hydroids the better to disguise themselves.

In other cases the often vivid colouring of animals like

anemones, many worms, starfish, or sea squirts, appears to have no value to the owner from the point of view of protection at any rate.

There are quite definite differences between the colours of animals inhabiting different depths in the ocean as is shown clearly in Plate 70. This has long been known to sailors and fishermen ; they know that the fish from the surface of the sea in tropical regions are usually sky-blue, whereas the deep-sea fish are always darkly coloured, black, brown, violet or red. During the cruise of the *Michael Sars,* hauls made in the Sargasso Sea revealed the presence near the surface of blue flying fish, others of a silvery colour and the transparent young stages of such fish as the eel ; at depths of 300 metres fish with silvery sides and brownish backs were captured, while below 500 metres only black fishes and red prawns were found (Plate 71).

It is noteworthy that these black fishes and red prawns only live in the regions where no or very little light can penetrate, living nearer to the surface in the Norwegian seas than in the tropics owing to the slighter extent to which light penetrates in the former. Another point of interest is that different species of the same genus, or even different varieties of the same species, which live at different depths are differently coloured, those from the greatest depths having the greatest and darkest pigmentation. The fishes from the abyssal region where there is no trace of light whatever appear to be usually brown, blue or violet, though what part pigmentation can play in the lives of animals always surrounded by impenetrable darkness it is impossible to say.

The connection between light intensity and colour in marine animals is difficult to explain ; in some cases the colour produced may be protective but this is only the

result—possibly a quite incidental one—and not the *cause* of the colour produced. It is highly probable, though it has yet to be definitely proved in all cases, that the pigments of animals are not produced by themselves but are manufactured from vegetable substances which they eat. The exact course which this manufacturing process may take and so the colour of the resultant pigment, appears to depend on the intensity of light. According to one theory feeble light is sufficient for the production of red pigment which may be converted into yellow or white pigment under the influence of light and perhaps other influences. Blue pigment is also produced from red when light is present but is also destroyed by light, so that blue animals are only maintained that colour because the production of pigment keeps pace with its destruction. But we have little definite knowledge on this most important subject which presents problems for the solution of which the combined efforts of biologist and chemist will be necessary.

Phosphorescence

Although many land animals, such as the glow-worm and firefly, are able to produce light so that they glow at night, this power of phosphorescence, or "bio-luminescence" as it is better called to distinguish it from light produced by the mineral phosphorus, is very much more widespread amongst marine animals. So common is it that it has aroused interest from the earliest times and many theories have been advanced in the attempt to explain the mystery of its production. For instance the explorer Franklin thought that phosphorescence in the sea was due to friction between the salts producing tiny electric sparks. This and other views are now of merely historic interest for, though the power of bio-luminescence is possessed by

most diverse animals and is displayed in many different ways, yet the actual production of light is the result of a chemical process which is identical in all cases. As long ago as 1667 the great chemist Robert Boyle found that bio-luminescence could only take place in the presence of air while, owing to the work very largely of an American physiologist, Professor E. Newton Harvey, we now know that the light is produced as a result of the oxidation of a substance called luciferin. When this combines with oxygen, light is produced, the luminescent reaction being probably represented by the following equation :—

Luciferin + Oxygen = Oxy-Luciferin + water (+ light).

The reaction is essentially the same as any other oxidation, for example that which occurs when a candle is burnt, but the energy produced takes the form of *light only*. This is one of the most striking properties of this animal light—it is *cold*, being unaccompanied by heat of any kind and is consequently more efficient than any of the forms of light which we can artificially produce, in all of which there is an invariable waste of energy owing to the accompanying production of heat.

But besides the luciferin, a second substance known as luciferase is invariably present when light is produced. This is an enzyme or ferment—belonging to the same class of substance as the ferments which enable us to digest our food—and takes no direct part in the production of light but acts as a kind of chemical lubricant assisting in some mysterious fashion in the union of the luciferin with the oxygen. Both luciferin and luciferase can be isolated from the animals which produce them so that it is possible to produce animal light in the laboratory and experiment with it in various ways. When the two substances are placed in a test-tube together, there is a momentary glow near the surface, where alone there is available oxygen,

but if the tube is shaken further oxygen is admitted and more light is produced either as a glow or as a sudden flash of light.

The oxy-luciferin can be deprived of the oxygen with which it has united—can be "reduced" in chemical phraseology—and so converted into luciferin again, and can then be used, when luciferase and oxygen are present, to produce more light. This process may apparently also go on in nature, there being a continuous change in the light organs of some animals from luciferin to oxy-luciferin with the production of light and then back again.

Certain bacteria are the lowest form of life to produce light. They are responsible for the light which appears on dead fish, and they occasionally invade living animals giving them a luminous appearance. According to a certain school of investigators similar bacteria live within the luminous organs of many animals and are the cause of the light produced there. Of the single-celled animals, the Protozoa, two especially, *Noctiluca miliaris* and *Pyrocystis noctiluca*, have exceptional powers of phosphorescence (Fig. 38). They have no special organs for light production but contain innumerable minute granules which are responsible for the luminescence. The presence of these animals

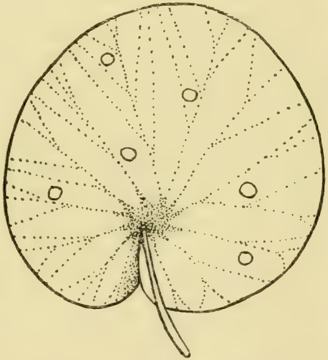


FIG. 38.—*Noctiluca miliaris*, a flagellate protozoan which is phosphorescent, greatly enlarged.

in countless numbers in the sea gives rise to that general phosphorescence, or "burning of the sea" as it was called by earlier observers, which has probably been noticed by everyone who has had much experience of the sea by night. Noctiluca is especially abundant in the plankton during late summer and autumn and in this season the prow of a boat cuts a silvery line through the water—often of such brilliancy that even in the dead of night a newspaper can be read by the light it casts. Noctiluca itself is pinkish in colour and may be thrown upon the shore in such numbers as to form a coloured layer along the beach, the shore water resembling "thick tomato soup."

According to Murray and Hjort, the Norwegian fishermen distinguish between "dead phosphorescence" and "fish phosphorescence," the former resembling "the stars in a clear sky, myriads of minute nearly invisible points emitting a scintillating light, now increasing, now decreasing, in intensity" and being produced by Noctiluca and similar protozoa. The second type, the result of rushing movements of large fish or squids which cause the phosphorescent animals momentarily to glow, is more like a dull glow of light which suddenly lights up and then dies out completely.

Many jellyfish have the power of general luminescence appearing as round balls of white fire in the sea. Those seen and described by travellers in the warmer seas are often of great size, and the late Professor Herdman describes how, when at anchor on the pearl banks of the Gulf of Manaar, "in an intensely dark night, I saw the black sea around us in all directions lit up by an innumerable assemblage of what looked like globes of fire, waxing and waning in brightness, all simultaneously glowing and then fading away into darkness, and after a few seconds lighting up once more. This periodic display continued for

about an hour and then disappeared." In our own seas the most vividly phosphorescent jellyfish is the rounded *Pelagia noctiluca* (Plate 73) which is however much more abundant in the Mediterranean. The method of light production is probably similar to that of Noctiluca only on a much larger scale, there are no special light organs but a stimulus of any kind, such as that caused by the passage of another animal, causes the whole animal to glow with light. Another animal related to the jellyfishes and even more intensely phosphorescent is the Sea Pen, *Pennatula phosphorea* (Plate 73), which lives in mud off the west of Scotland and Scandinavia. When brought to the surface the slightest touch at any part will cause that region to light up in the darkness, the light then spreading from branch to branch until the whole is aglow. The large Sea Pen, *Funiculina quadrangularis* which may be six feet long, is, according to Professor Herdman, especially phosphorescent along the main stem which, if gently touched, glows with light which travels up and down like a flickering flame.

The most phosphorescent of the worms is, peculiarly enough, one called Chætopterus which spends its whole life hidden in a parchment-like tube buried in mud with only the head end protruding (Fig. 39). This animal produces a luminous substance mixed with mucus over almost the entire surface of the body. The light in this case in usually violet or bluish green, and a similar colour is given by many other small marine worms. In some of these, such as one called Odontosyllis from Bermuda, the production of light is concerned with reproduction, light being produced only during the reproductive season when the animals swarm in the sea for mating, and never at other times.

When we come to the crustaceans we find much more

highly developed powers of light production, definite light organs, some of them very simple but others of great complexity, being found in many of these animals. In some of the simplest cases, luminous slime is produced by little glands above the mouth, the substance discharged glowing with a yellow light. A few of the ubiquitous Copepods of the plankton are luminescent, when disturbed they throw off a cloud of luminescence produced by glands spread over the surface of the body. Some prawns and the shrimp-like Euphausiids—comparatively large planktonic crustaceans which furnish valuable food for the herring—have very complex light organs, so intricate indeed that they were originally thought to be additional eyes! There are usually ten light organs, a pair behind the eyes, two pairs on the side of the body and four on the under side of the tail, and each of these consists of a layer of light-producing cells, behind which is a reflector backed by a layer of pigment which prevents any of the light from being wasted by passing into the body, while in front is a lens which focuses the light. Into the light-producing area

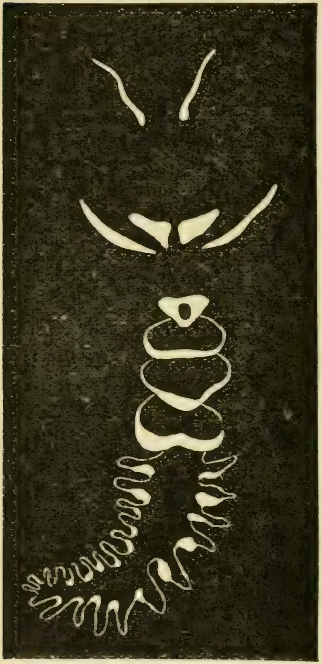
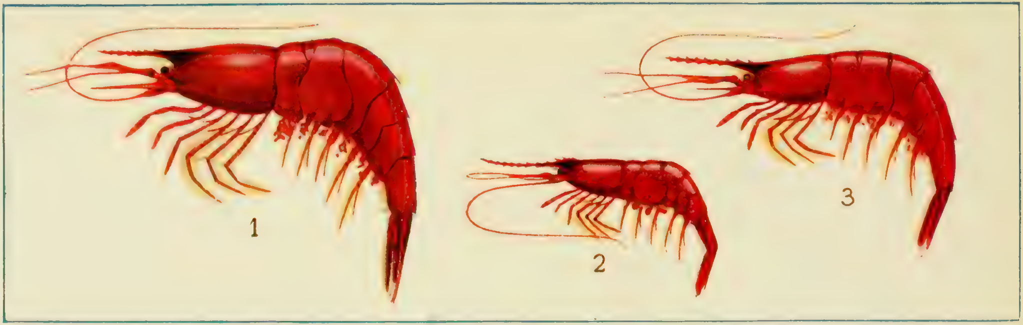


FIG. 39.—*Chætopterus variopedatus*, a phosphorescent marine worm as seen in the dark (Nat. Size).

Pl. 70. *N* 190.

Showing colours of animals from different depths, from surface downwards. (p. 184).

1. *Rhizostoma pulmo.*
2. *Janthina fragilis.*
3. *Glaucus eucharis.*
4. *Anomalocera patersoni.*
5. *Halosphaera viridis.*
6. *Chrysaora mediterranea.*
7. *Gaetanus kruppi.*
8. *Gigantocypris agassizi.*
9. *Eucopia australis.*
10. *Atolla chuni.*
11. *Cyclothone livida.*



Deep-Sea Red Prawns. (p 184).

1. *Acanthephyra multispina.* 2. *Systellaspis debilis.* 3. *Acanthephyra purpurea.*

Pl. 71. *N* 191.

Deep-Sea Black Fish. (p. 180).

(*Melanostomias Valdiviae*). $\frac{3}{4}$.

passes a nerve which controls it—for the luminescence of these animals is under direct control and the light organs can be turned off and on at will like an electric torch. The organs are also well supplied with blood for, since they are shut off completely from the water, they are unable to get the oxygen, which, as we have seen, is necessary for the production of light, except from the blood stream. A typical light organ of this kind is shown in section in Figure 40.

In the chapter on boring life we discussed the bivalve

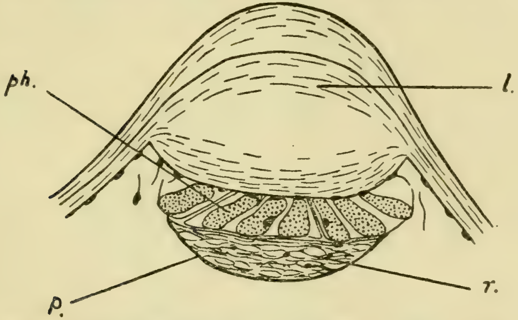


FIG. 40.—Light-producing organ of a crustacean, Sergestes. *l.*, lens of several layers; *p.*, layer of dark pigment behind reflector; *ph.*, photogenic cells where light is produced; *r.*, reflector. (Modified after Terao.)

mollusc known as the Piddock (*Pholas*) (Fig. 41) which bores its way into rock where it lives with only the tips of its siphons projecting into the water. This creature, strangely enough, is one of the most luminescent of marine animals, a fact which has been known from very early times. There are no special organs but light is produced within minute glands present in five areas on the skin and spreads from these all over the surface of the body. The light is a greenish blue and very powerful. Passing

on to the most highly evolved of the molluscs, the group which includes the octopus and cuttlefish, we find that luminous organs are both common and in the highest degree elaborate, especially in the squids which swim near the surface and sometimes in those from deeper water (Plate 74). The octopus and its immediate allies are never luminescent. Though occasionally the light organs are simple, they usually consist of a light-producing area backed by reflectors and a protecting coat of pigment; very similar to those we have already described for the crustaceans, the light being focused by a lens and the whole protected by a cornea, just as in the eye. Some of these cuttlefish from the deep sea have over twenty light organs in various parts of the body; most of these throw a white light but a few are deep blue, two near the eyes are usually sky-blue while two organs on the under end of the body—like rear lights—are most appropriately red. The different colours are probably the result of coloured screens in front of the light organs.

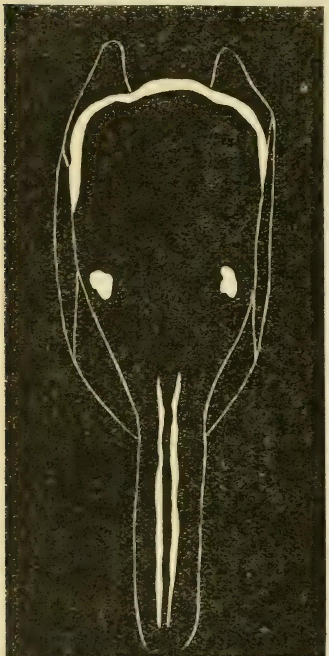
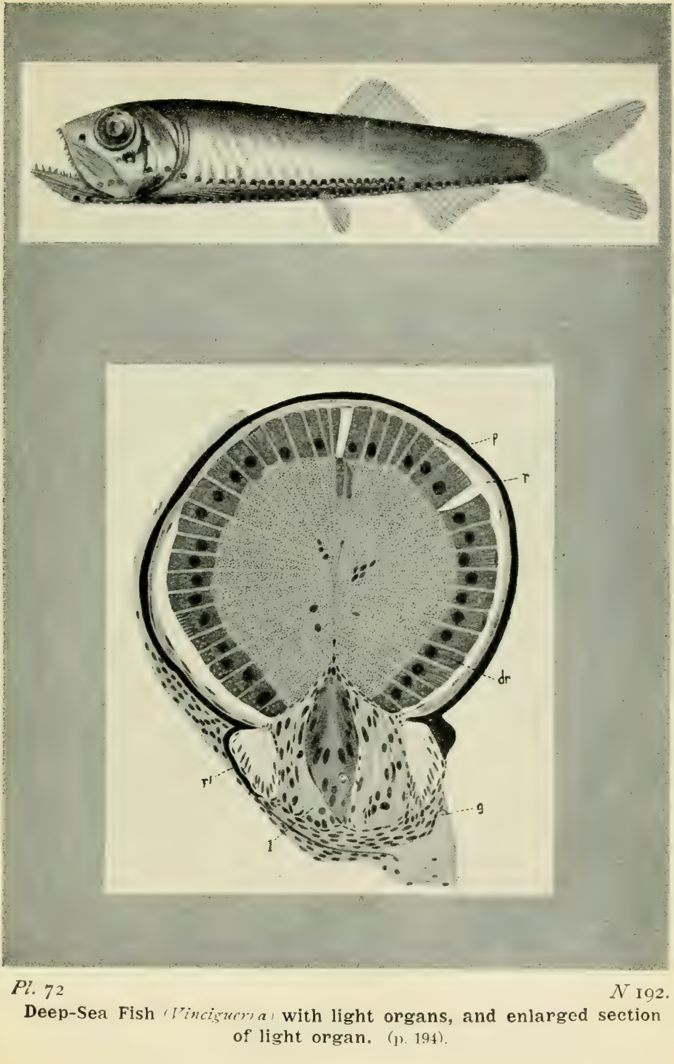


FIG. 41.—The Piddock, *Pholas*, a rock-boring bivalve, showing phosphorescent regions as seen in the dark (Nat. Size).

The interesting Tunicate named Pyrosoma, a glass-like



Pl. 72 *N* 192.

Deep-Sea Fish (*Vinciguerria*) **with light organs, and enlarged section of light organ.** (p. 194).

Pl. 73. *N* 193.

Pennatula phosphorea.

A Luminous Sea pen, $\frac{3}{4}$.

(pp. 70, 189).

Pelagia noctiluca.

A Luminous Jellyfish. Natural size.

(p. 189).

transparent mass of small animals which unite one with another to form a hollow cylinder one end of which is closed, is found drifting about near the surface of the sea and forms a conspicuous member of the plankton in such regions as the Mediterranean and tropical seas. Each member of the colony has two light-producing glands and the light they give out is said to be red in some and blue in others, the whole colony when stimulated blazing with thousands of these tiny points of light. Moseley, one of the naturalists on the *Challenger*, states that, after a Pyrosoma more than four feet long had been captured, "I wrote my name with my finger on the surface of the giant Pyrosoma as it lay on deck in a tub at night, and my name came out in a few seconds in letters of fire."

At one time it was thought that luminous fishes were especially common in the deepest seas, regions of utter darkness, the light being used to assist them in their search for food. This is now known to be incorrect for, though the fish living on the surface, such as the herring or mackerel, never display luminescence, yet this power is commonest in fish living at moderate depths, on the bottom or in the intermediate regions. Light organs are apparently commonest in fish which live in the upper 500 metres of the warmer seas, although there are notable exceptions, for example, a remarkable fish called Harpodon which lives in rivers and estuaries in India and, when caught, displays the most vivid phosphorescence, and another called Photoblepharon found in pools of fresh water in quarries and the craters of extinct volcanoes in Malaya. The actual organs vary a great deal in both structure and position. They may be mere pits and channels for the production of a luminous slime, such as are found in some of the deep-sea Macruridæ, or they may be complex organs like the natural lamps we have described in some of the

crustaceans and squids. They may occur on almost any part of the animal, and are often arranged in rows along the sides of the body (see Plate 72) though they are frequently found in the head region, as in the case of the deep-sea anglers with their waving lamps for the attraction, possibly, of prey. One very remarkable fish has no eyes but instead a large light organ under the frontal bones within the skull.

The reason for the production of light in these different marine animals is in most cases a complete mystery. We can only hazard a guess as to what part it plays in the life of the animal. Thus it is difficult to see what use luminescence can be to bacteria, Noctiluca, jellyfish, or the Sea Pens, it is probably merely a by-product of the normal activities of these creatures. The case of the concealed animals, such as the Piddock or the Tube-worm, *Chætopterus*, presents almost equal difficulties though it may be that the light serves to attract to their burrows the tiny animals on which they feed. In other cases the light may help members of the same species to recognize one another or assist the females in attracting the males during the mating season. It appears that luminous secretion may be discharged into the water to distract a pursuing enemy, while in other cases the sudden flashing of light from the more complicated light organs may perhaps protect the animals by giving warning that it is harmful or distasteful as food, in much the same way as the brilliant colours of some terrestrial animals are said to afford warning of the unpleasantness of their owners. Of course it is possible that there is truth in the old belief that the light organs of the deep-sea animals which look so much like little lanterns are actually used for the same purpose and help them in their search for food. But we can be certain of nothing and the production of animal light is, and seems

likely to remain for some time to come, as deeply mysterious as it is fascinating.

We must not leave this subject without referring to the practical use to which the presence of phosphorescence is put by the natives of the Banda Islands who employ the luminous organs of a fish as bait in fishing and with a success which justifies their enterprise.

CHAPTER IX

Feeding of Marine Animals

Food is the first necessity of life, and nowhere is the struggle to obtain it keener than in the sea ; every possible source of food has been exploited by one type of animal or another, so that the study of the multitudinous devices for obtaining food of one sort or another which have been evolved as a result of the keen struggle for existence forms one of the most fascinating branches of marine biology.

The food in the sea may be divided into two groups; there are the dissolved salts and gases in sea water, such as the manurial nitrates and phosphates, carbonic acid gas, etc., which form the food of plant life, both large seaweeds and microscopical diatoms ; and there are the actual plants and animals themselves, both living and dead, and also while in the process of disintegration by bacteria. It is the organic substances of which these are made up—as opposed to the inorganic salts in the sea water—which form the food of the animals. They are divided into three groups of substances, fats, proteins and carbohydrates, all three of which—together with minute traces of those little known, but all-important, substances known as vitamins—are essential to the life of the animal, though the relative proportions vary for different kinds of animals. According to a German scientist named Pütter, the animals also obtain nourishment from dissolved organic substances in the water, but this somewhat fascinating theory has never been fully proved.

One may roughly divide animals into herbivores, carni-

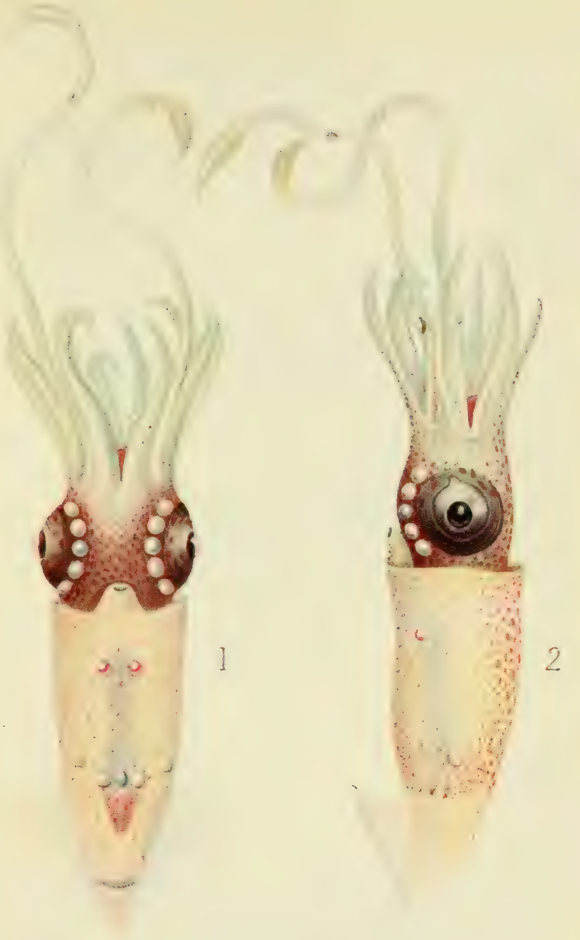
vores, and those which feed indiscriminately upon any kind of food ; but owing to our lack of knowledge concerning the food of many marine beasts, it is perhaps better to divide up marine animals according to the method by which they feed rather than the particular substances which they eat. Thus we may divide animals into those which possess the means for feeding on fine particles, on large masses or living prey, and finally for sucking in fluid food. To these must be added the parasites which prey upon other animals and those remarkable cases of intimate union between two animals or between an animal and a plant, the two being entirely or partly dependent one upon the other, a condition known as " symbiosis," from two Greek words meaning " together " and " life."

Invertebrate Animals living on Fine Food

The animals which feed on microscopic plants and animals or on fine particles in suspension in the sea are usually either sessile creatures attached to the bottom, animals which cannot go in search of prey but have to take what they can from the water which flows past them, or else they are small animals of the plankton. Many of the mechanisms with which they are provided for collecting their finely divided food are extremely complicated, and the mode of feeding in some of these animals is the most elaborate found in the animal kingdom.

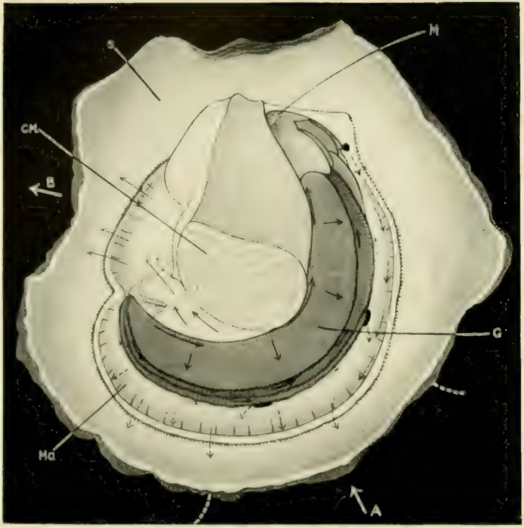
A very large number of these animals create a stream of water by means of tiny, rapidly moving hairs, known as " cilia " or " flagella," the food particles being sieved out and swallowed. The simplest mechanism of this type is found among the sponges which are honeycombed with a series of fine canals, through which water passes to be later expelled by a large central opening or " osculum," all food particles in the water having been seized and absorbed

during the process. Those worms which live in calcareous or parchment-like tubes bear round their head end a crown of foliaceous tentacles, often of great delicacy and beauty, which normally wave about freely in the water, but which are withdrawn in a flash on the approach of enemies (Plate 77). These tentacles are covered with cilia and also with a sticky substance in which fine particles are entangled, being later carried to the mouth by currents produced by the beating of the cilia. But it is the bivalve molluscs, such as the oyster and mussel, which have carried this method of feeding to the greatest degree of perfection. As shown in Plate 75, on either side of the body there are two pairs of delicate membranes known to scientists, owing to the mistakes of earlier naturalists, as gills, and to the oyster merchant as the "beard," but which really form an apparatus for collecting food. Each of these membranes is double and consists of a great number of fine filaments laid side by side and covered with rows of cilia. The cilia on the sides of the filaments beat inwards so that they cause a strong current of water to pass into the interior of the membrane and so upwards and out of the body. The cilia beat continuously so that as long as the shell is open there is a continuous stream of water entering at one point, passing through the membrane of the gills, and then out at another. Only the water passes through the gills ; all particles in suspension are retained on the surface, where they are entangled in the sticky mucus there produced and carried by the cilia on the outer surface of the filaments to the edge or base of the gills, whence they are conducted by further cilia to the mouth, which is protected by two pairs of triangular flaps known as "palps." These are ridged on their inner surfaces and covered with many series of cilia beating in every possible direction, the whole forming an extremely complicated, but very efficient, mechanism for sorting out the particles,



Pl. 74. O 198.

Deep-Sea squid (*Thaumatolampus diadema*) **with luminous organs,** × 2.
(p. 182)
1. Underside. 2. Side view.



Pl. 75. *O* 199.

Diagram of Oyster, showing manner of feeding. Right half of shell removed A., ingoing current of water; B., outgoing current; C.M., closing muscle; G., gill filaments; M., mouth; Ma., mantle; S., shell; Arrows show direction of currents. (p. 198).

Whelk opening oyster shell by inserting edge of its own shell between valves of oyster shell (after Colton). (p. 206).

rejecting the large ones which accumulate just within the shell until the animal closes its shell quickly when they are shot out, and only allowing the smallest ones to enter the mouth and pass into the stomach.

The sea squirts feed in a somewhat similar manner, water being drawn in at the one opening and rejected by the other after having been sieved through a delicate lattice work. So fine is this lattice that, in a medium-sized sea squirt, it has been estimated that there are almost 200,000 openings and about double that number of rows of cilia, the beating of which creates the current. Here again the food particles

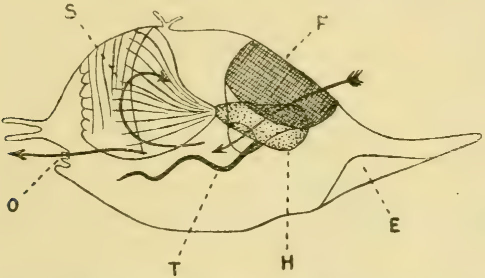


FIG. 42.—Oikopleura in " house." E., opening through which animal escapes from house; F., fine mesh guarding opening through which water is drawn; H., head end of animal; O., opening through which water is expelled; S., sieve in which food is collected; T., tail of animal. Arrows show direction of water currents in house (x 5).

are entangled in a sticky substance and carried to the mouth by special tracts of cilia. Near relatives to the sessile sea squirts are the tiny floating Appendicularians, which form part of the plankton. They feed in a most amazing manner. They do not catch the food directly themselves, but form an elaborate gelatinous " house " much larger than themselves, within which they live. This " house " is really a complicated apparatus for straining sea water and is illustrated in Figure 42. As a result of the

beating of the tail of the occupant, water is drawn in on the upper side of the house through a pair of openings guarded by a fine network and the extremely fine particles still remaining in suspension are collected by a very complicated sieve within the house. The food is then drawn into the mouth of the animal, again by the aid of cilia, while the strained water passes out. The house soon becomes useless on account of accumulations of particles which effectively clog it, and it is then abandoned by the animal—after perhaps being in use for only a few hours—and a new one in all its intricate detail constructed in half an hour or so! Other members of the plankton which feed exclusively by means of cilia include some of the delicate Pteropods or "sea butterflies."

Many of the smaller crustaceans have feathery limbs for collecting finely-divided food. The common barnacles (Plate 78) are provided with six pairs of delicate limbs fringed with fine bristles, which are alternatively shot out from the shell and withdrawn, sweeping through the water like a casting net during the latter phase. The process can easily be observed by placing acorn-barnacles collected from the rocks in a basin of sea water and cannot fail to be admired for the grace and precision of the movements. The barnacle literally "kicks its food into its mouth." Many of the smaller planktonic crustacea, such as copepods, create by the movement of their swimming legs currents in the water all around them, in which particles are drawn in between the limbs and then forward along the under side of the body, where the water is filtered and the particles so collected pushed into the mouth. Some of them feed exclusively on diatoms, others on smaller copepods, and others again on a mixture of the two.

The small sea gherkins (such as Cucumaria and Thyone) which live in holes and cracks in the rocks and have a ring

of branching tentacles around their mouths, have an original manner of feeding (Fig. 43). The tentacles are usually projected out of the rock and, as they are covered with slime, food quickly collects upon them ; but there are no cilia to carry the food to the mouth, instead the tentacles are deliberately curved inwards and pushed to their fullest extent into the mouth and then slowly withdrawn, the food being scraped off by means of a pair of short Y-shaped tentacle sat the side of the mouth. One tentacle after another is pushed into the mouth in regular sequence and sucked clean—exactly like a child sucking jam off its fingers! One of the marine snails called Vermetus, feeds in a manner peculiar to itself. It has largely lost the power of movement but uses the mucus, which such creatures normally employ to lubricate their movements, to catch its food, throwing out a sheet of sticky mucus in which fine particles and animals are entangled, and after a time drawing this with the collected food back into its mouth.

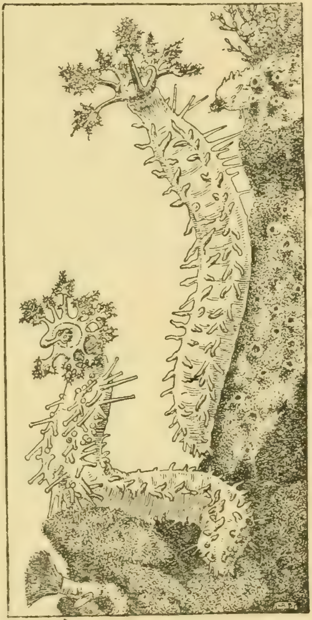


FIG. 43.—The seacucumber, Cucumaria, feeding (x ½).

BURROWERS AND SCRAPERS

A great many animals (such as worms, and sea cucumbers)

live in mud, spending their days slowly ploughing through it, swallowing, as they go, large quantities from which they extract such nourishment as it contains, just as the earthworms do on land. The burrowing sea urchins feed in somewhat the same manner, but they pick up particles by means of special grasping tube-feet, which surround the mouth. Other animals of which the Shipworm is an example, obtain their food by boring ; while others again scrape off the various plants and animals which form a crust over the surfaces of the rocks. Of the latter type of feeders, the common sea urchins are examples, they hold on to the rock with their tube feet and bite off the food by means of five long teeth, which are supported in an intricate skeleton known, on account of its discoverer and shape, as Aristotle's lantern, which is shown in Plate 79. The muscles of the lantern force the teeth downwards so that they all come together beneath the mouth, biting off a circular piece of food, which is automatically pushed into the mouth.

Other animals which scrape their food from the surface of stones are the common shore snails, such as the periwinkle and the limpet, which crawl about by means of their big muscular feet. In common with other members of the snail family they possess a very characteristic feeding apparatus consisting of a long horny ribbon, made up of many rows of fine teeth, and known as the "radula" or lingual ribbon (Fig. 44). This is supported by a strengthening framework over which it is drawn backwards and forwards like a rope over a pulley. The whole mechanism can be withdrawn into the mouth when the animal is not feeding, but when in use is pushed out against the food which it rasps away by continuous backward and forward movements, each piece being pulled back into the mouth and further broken up by the help of jaws before it is swallowed. The radula is constantly being worn away, but

is just as steadily replaced, new material being added to the hind end of the ribbon continuously. It varies very much in different animals depending on their particular type of food, thus in the animals we have been discussing it is broad, the better for scraping over wide surfaces, while in the carnivorous snails, which we shall discuss later, it is much narrower.

Preying Animals

Great numbers of animals in the sea prey upon other animals either living or dead. All the anemones and jellyfish, in spite of their delicacy and great beauty, are really voracious carnivores. They seize their prey, which may be anything from worms to small fish, by means of their tentacles, which are armed with batteries of minute "nettle cells," each of which consists of a tiny bag filled with fluid and drawn out into a fine whip-like process which lies coiled within the bag. When they are touched by any animal these nettle cells explode and the thread, which is usually barbed, is shot violently out and into the body of the prey. The fluid in which the thread has been bathed is poisonous and some of this enters the wound causing paralysis. The prey is then pushed into the mouth and taken into the stomach, where it is digested with remarkable speed (Fig. 45). Many jellyfish will seize and swallow animals larger than themselves, seizing young fish with their delicate

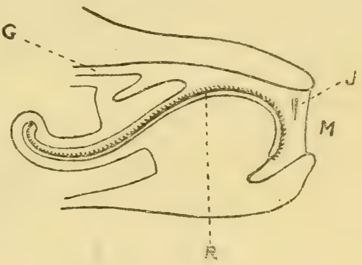


Fig. 44.—Diagram of Radula. G., gullet; J., jaws; M., mouth; R., radula, which can be pushed forward through mouth-opening.

tentacles and playing them like an angler. Starfish and brittlestars crawl about on rocks or in the sand and devour any suitable animal which they can find, the former seizing them with their tube-feet, and the latter wrapping them round with their very active arms. In both cases the prey is carried to the mouth and swallowed, but the common

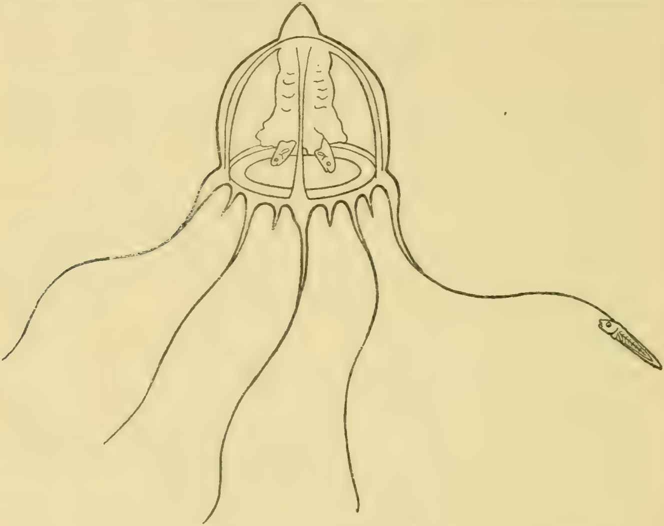


FIG. 45.—A medusa, *Neoturris pileata*, catching and feeding on young fish (x 2).

starfish is also able to feed on animals much larger than itself by the simple and convenient process of protruding its stomach over any animal which it cannot swallow. They consume great numbers of bivalve shellfish over which they hunch their bodies, gradually forcing the shell valves open by the continuous pulling action of their tube-feet for, though the closing muscles of the bivalve shell are

much more powerful than the tube-feet, yet they soon tire, and finally the steady pull of the starfish conquers and the shell begins to gape. As soon as this happens the starfish extrudes its stomach through its mouth and forces it into the opening (Fig. 46), where it first probably poisons and later certainly digests the soft body of the prey. It is this habit which makes the starfish the greatest pest on oyster and mussel beds. Starfish can even attack the apparently vulnerable sea urchin by forcing their stomachs down its throat apparently quite regardless of the teeth.

Many worms are carnivorous, seizing their food by means of horny jaws and usually swallowing it whole. Whelks and their relatives live on carrion, often dead or dying bivalves; their mouths are situated at the end of long probosces

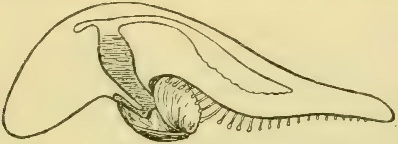
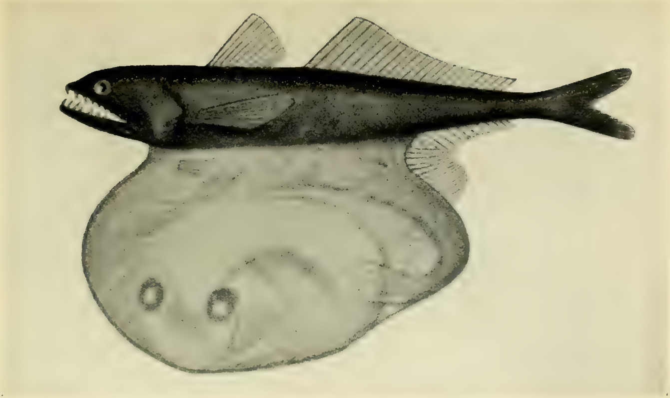


FIG. 46.—Diagram showing how a Starfish feeds on its prey. (Modified after Hirsch.)

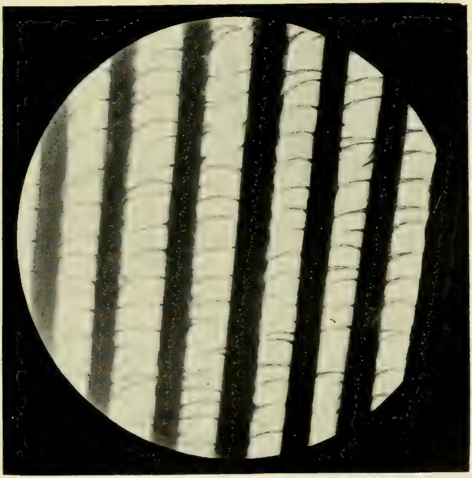
which can be extruded for a considerable distance, and in this manner the inside of a mussel can be cleaned out, the flesh being scraped into the mouth by the radula. Many similar animals are able to attack living bivalves by boring through their shells either mechanically by means of the radula, or else chemically, the animal pouring out strong acid which eats through the calcareous shell. As soon as the opening is made the long proboscis with which all these carnivorous snails are equipped is pushed into the soft flesh, which is probably poisoned and then very quickly consumed. Others again open the shells of oysters by moving on to them and waiting until the oyster opens when,

by a sudden twisting movement, they drive the edge of their own shell in between the open valves, which are thus held apart sufficiently to allow the proboscis to be pushed in (Plate 75). Others again grip the shell of their prey with their broad feet and force the edges together, cracking off pieces near the edge until a hole is made large enough to allow the proboscis to enter. The sea slugs frequently browse on stationary animals ; thus the sea lemon, Doris, spends its life scraping sponge into its mouth with its broad radula ; the beautifully coloured Æolis feeds on anemones, being apparently quite unharmed by the nettle cells. It is a very remarkable fact that these nettle cells, after they have been swallowed, are transported into the little projections on the back of the Æolis, where they establish themselves and in which they are always found, so that the older naturalists thought they actually developed there. Their value to the Æolis, if any, is not very clear, though they may help to protect it. One little sea slug called Calma feeds exclusively on the eggs and embryos of shore fishes, which are laid on stones and shells. When feeding, its face fits like a hood over the egg, which is slit open by the narrow, saw-like radula and the contents swallowed. There is another type of carnivorous marine snail, the boat-shell, Scaphander, which swallows small bivalves whole and then crushes them to pieces in a special gizzard lined with limy or horny plates and worked by powerful muscles.

The active pelagic squids pursue shoals of fish near the surface. The octopus and cuttlefish lie concealed, the one in crevices among rocks and the other in the sand, and dart out upon their prey, usually fish or crabs, which they seize by means of their tentacles armed with suckers. They are particularly careful when attacking crabs to seize them from behind so that these are unable to defend themselves by means of their claws, which are gripped firmly by the



A voracious Deep-Sea fish *(Chiasmodus niger)* with a fish many times its own size in its stomach, $\times 1\frac{1}{3}$. (p. 209).



Pl. 76. *O* 206.

Gill-rakers of Mackerel *(Scomber scomber)*.

Showing fine spines for sieving off the plankton on which it feeds, $\times 15$. (p. 208).

Pl. 77 O 207.

Amphitrite figulus, slightly reduced. (pp. 38, 198.)

suckers and held away from the body of the attacker. The mouth of the octopus and squid is in the centre of the arms and possesses a pair of extremely powerful horny jaws (Plate 78), shaped like the beak of a parrot, and also a small radula. After the prey has been seized it is bitten into by the jaws and a poison poured in which quickly kills it. The flesh is then dissolved away by means of digestive juices produced by special glands and the fluid sucked in through the mouth. In this manner the shell of a crab is entirely cleaned out and then discarded.

The crab and lobster family are mainly scavengers, feeding on whatever they can obtain, dead or alive, plant or animal. They seize their food by means of their powerful pincer-like claws in which it is first crushed and then pushed towards the mouth which is guarded by a whole series of jaws and other appendages by means of which the food is torn up and shredded out until it can be easily swallowed. The stomach of these animals is lined with a horny substance and has also three teeth which are worked by muscles attached to the shell and in such a way that all three come together in the centre of the stomach breaking up the food still further so that it can be digested by the animal.

Feeding of Marine Vertebrates

Broadly speaking, the fish may be divided into two classes, those which feed on the plankton, and those which feed on the larger swimming animals, or, more especially, the bottom-living animals. Of the former, the herring and mackerel are the best known and most important, both of them swimming about freely in mid-water. They feed by straining great quantities of water over the gills where the plankton, especially the small crustacean copepods, is collected in a sieve consisting of a parallel series of slender horny projections from the front side of each gill arch and

known as the gill-rakers (Plate 76). These are best developed in the Basking shark, a tropical fish which spends its life near the surface feeding on small animals. The bottom-living fish, such as the flatfish and rays, live upon the worms and shellfish of various kinds which they seize and crush up with their powerful jaws. It is because the Dogger Bank has an exceptionally rich fauna of bivalve molluscs which are found in great patches sometimes fifty miles by twenty, and at a density of between 1,000 and 8,000 per square metre, that the Bank forms such an ideal region for the growth of plaice. The rays are often able to crush up the massive shells of the larger bivalves such as the oyster, one of their number forming the most serious enemy of the pearl oyster on the Ceylon beds—yet not an enemy to the pearl diver for this ray is the second host of the tapeworm, the early stages of which live in the pearl oyster and often form the nucleus round which pearls are formed. Other rays do serious damage to the deeper-water oysters off the eastern coast of North America. More actively swimming fishes such as the cod and haddock also feed on the bottom animals. Other fishes pursue their small relatives ; the herring shoals for instance are invariably accompanied by great numbers of dog-fish which annually devour large numbers of herring. More unique are the feeding habits of the Angler, a sluggish fish which lives on the sea bottom and has a short stumpy tail, a comparatively small body and an immense head and broad mouth with inwardly pointed, hinged teeth. Above the mouth is a long tentacle with a rag of skin at the end which may be phosphorescent ; the Angler lies perfectly still with its huge mouth wide open and appears to use this tentacle as a lure, for, so far from having to hunt its prey, fish of all kinds, impelled by curiosity or desire for food, come to inspect the lure and are seized in a moment

in the open mouth, the recurved teeth of which effectively prevent it from escaping. Diving birds have even been discovered within Anglers. Some of the deep-sea Anglers have a highly developed luminous organ at the tip of the tentacle which can perhaps flash on and off at will. Other of the deep-water fish have huge mouths and an unlimited capacity for food, their stomachs being capable of such expansion that their owners can swallow animals larger than themselves (Plate 76).

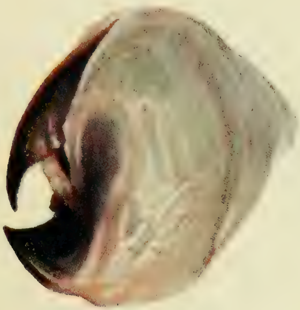
The feeding organs of fishes naturally vary with the type of food. The wrasse, which feed on crustacea or molluscs, are able to crush them to pieces in their mouths by means of specially powerful teeth in the mouth and throat, but the young of the grey mullet which feed on fine particles and are reported to do considerable damage to the oyster beds, owing to the fact that they swallow great numbers of the free swimming "larvæ," have no teeth, really sucking in their food. The adults have only weak teeth and browse on encrusting weeds and the small crustaceans in them, the stomach forming a gizzard for the crushing up of this food. The Pipe-fishes also have a complete lack of teeth and indeed suffer from a kind of permanent lock-jaw; they live on minute crustacea which they take in by sucking action. The beautiful green or blue Kakatua of coral islands has a hard beak with which it rasps the surface of coral rocks for encrusting sea weed. It was originally thought actually to feed on the corals themselves. The Trigger-fishes have jaws and teeth of exceptional strength, those of one species, *Balistes capriscus*, being shown in Plate 79.

The feeding of whales forms a strange paradox, the largest of all feeding on plankton, straining it through the frayed fringes of their whalebone plates, while the rather smaller Sperm whales feed on giant deep-sea squid which

they seize with their powerful teeth. Seals and sea-lions feed on fish which they pursue and capture in large numbers, but walruses live on shellfish which they scrape up by means of their large tusks.

Suckers and Parasites

The only type of feeders which we have not yet considered are those which live by sucking in fluids or soft tissues. These are not numerous in the sea except as parasites, although a few animals such as some of the little nudibranch molluscs or sea slugs which live on green weed are suckers without being parasitic, merely drawing in the soft green tissues. There are a great many parasites which do not dwell within the body of the animal on which they are parasitic, but either fix themselves permanently or move about on the outside of the body. These are known as ectoparasites to distinguish them from the endoparasites which live *within* the body of the host. There are many examples of ectoparasites in the marine world, the commonest being copepod crustacea, relatives of the freely swimming copepods which abound in countless numbers in the sea, forming, as we have seen, the principal food of fish such as mackerel and herring. These are usually parasitic on fish and assume all manner of strange shapes; a few of them can be recognized as copepods but in the majority it is only a knowledge of their life-history in the early stages which has enabled us to classify them as copepods. Examples of different types of these parasites are given in Plate 81. Some of the less degenerate kinds move about freely on the surface of their host fish, probably living on the mucus and soft skin, but the more degenerate ones bore into the tissues of their host or fix themselves to the gills, or soft skin round the eyes, and have usually



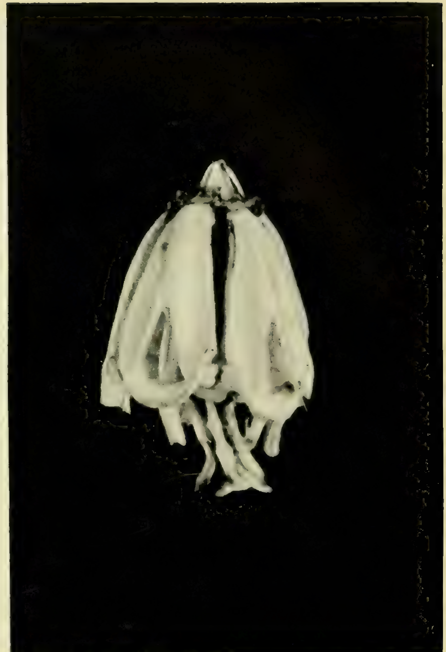
Pl. 78. () 210.

Jaws of Squid. × 2. (p. 207).

Goose Barnacles (*Lepas anatifera*), Natural size.
1. Legs fully expanded. 2. Legs half out. 3. Shell closed.
(p. 200).

Pl. 79.

Teeth and Jaws of Trigger-fish.
Balistes capriscus.
Natural size.
(p. 209).



Pl. 211.

Aristotle's Lantern.
Teeth of Sea Urchin.
Natural size.
(p. 202).

piercing and sucking organs by means of which they feed on the blood and soft tissues of the fish.

There are also marine leeches which suck the blood of fish. The most exalted of marine parasites is the hagfish, one of the Cyclostomes and a lowly ally of the true fish, which fixes itself by a single tooth into the flesh of its victim and then rasps away the tissues by means of its scaly tongue, sucking in the food as it goes.

The most degenerate types of parasites have completely lost their feeding organs, they lie in the body cavity or gut of their host bathed in nutrient fluid which they absorb directly through the surface of their bodies. There are innumerable examples of which only one—perhaps the most striking—example can be mentioned here. It is quite common to find on the under side of the bodies of various kinds of crabs, a small round brownish mass—rather like a tumour but in reality a parasite called Sacculina (Plate 80). It is practically without structure, just a bag containing reproductive products with a branching mass of roots which penetrate the body of the crab in all directions and absorb nourishment from it. Strangely enough this parasite is a lowly relative of the animal in which it lives. It is a crustacean most closely allied to the barnacles, a fact which has been established by study of its life-history (Plate 80). The eggs, which are discharged freely into the sea from the parent parasite, hatch out into minute pear-shaped creatures, each with three pairs of legs, a single eye, and bearing a little shell exactly like the similar stage of any other crustacean except that they have no stomach or intestine. These minute "Nauplius" larvæ (Plate 80) swim about in the sea for some weeks when they moult and become "Cypris" larvæ which have a hinged shell almost enclosing the body, a pair of feelers, and some six pairs of swimming legs. For a little time longer they

continue to swim about and then must either die or find a crab on which to settle. In the latter case they attach themselves by means of tiny hooks on their feelers to hairs on the body of the crab, the feelers penetrating the base of the hair after which the legs of the Sacculina are cast off and the rest of the body degenerates into a little mass which passes through the hollow feelers into the crab's body. It is carried in the blood stream until it reaches the middle of the body where it attaches itself near the stomach, sending out roots in all directions, while the main mass grows larger and larger until it gets pressed against the inside of the shell about the middle of the under side of the body. The next time the crab moults the parasite pushes its way out before the new shell has had time to harden and there assumes its final tumour-like shape.

The parasite usually lives some three or four years and from the time it escapes to the exterior the host crab never moults, all its reserve of food and strength go to supply the needs of the parasite. It is only when the Sacculina dies that the crab is able to resume growth and moult at the usual intervals. It is a very interesting fact that male crabs which are infected in this way gradually assume the appearance of females, developing a broad instead of a thin abdomen, smaller claws, and certain small legs on the hinder end of the body which are normally only possessed by the females. About seventy per cent. of infected male crabs show various stages in this process but infected females on the other hand show no signs of becoming like males. An elaborate theory of the causation of sex has been based on this sex change in parasitized crabs. Details of this are out of place here, but the gist of it is that the presence of the parasite causes the active male to lead the more sedentary life of the female, and to eat more in order to counteract the abnormal drain on its

resources. This accumulation of reserve food affects the vital functions of the animal in such a way as to lead to the appearance of female characteristics, even to the production of eggs!

Symbiosis

In a previous chapter we discussed the case of animals which lived together, such as gall crabs in corals, and hermit crabs in anemones or with anemones growing on their shells. This mutual association has not only to do with defence but with food—thus the anemone in return for the protection it affords the hermit crab is able to seize fragments of food broken up by the crab, while in the more extreme case of the pea crab which lives within mussels or similar bivalves or within the large sea squirts, the crab intercepts the food collected on the latticed feeding organs of these animals, scooping into its mouth strings of food mixed with mucus. But there is a much more intimate form of association the object of which is also provision of food for one or both of the parties concerned. We may have two animals or an animal and a plant living in intimate union the one with the other to their mutual advantage, and often so dependent one on another that one or both cannot exist if separated from the other. This is the type of association known as symbiosis.

The commonest type of symbiosis is the partnership between an animal and minute, green, yellow or brown plants—single-celled Algæ—which are taken into the tissues of the animal in large numbers. Many of the simplest animals, the protozoa, especially the delicate Radiolarians, always contain these, as do some sponges, corals, and flatworms. The animals are always associated with a particular kind of alga which is called Zoochlorella if green and Zooxanthella if yellow. The advantage to

the plant in the association is not always clear but it is probable that it obtains valuable food material from the waste products of the animal it lives in. In the case of the animal the advantage is more obvious; in virtue of its possession of the green colouring matter chlorophyll, the plant, in the presence of sunlight, can manufacture starch out of the water and the carbonic acid gas it holds in solution, and this starch is utilized by the animal. The majority of corals which always contain symbiotic algæ appear to gain a considerable, if not the greater, part of their food in this manner. If other food is abundant the algæ are left undisturbed in the tissues of the coral but if that is scarce then the coral appears to digest the plants, a starved coral gradually digesting all its contained algæ.

The most striking case of this type of symbiosis is furnished by a small flatworm, Convoluta, only a few millimetres long, which lives on the sandy shores of north Brittany and the Channel Islands. It is bright in colour and occurs in large colonies which form green patches on the yellow sand, and is an animal of most regular habits, suddenly appearing from beneath the sand immediately after the tide has left it and disappearing just before the tide returns (Plate 82). The green colour is due entirely to the presence in the tissues of vast numbers of algæ. These are not present in the egg but the animals become infected in a very early stage in development, and if they are kept free from infection by artificial means they fail to develop properly and soon die. Although in early life it is able, like other flatworms, to feed on smaller animals the Convoluta soon finds that it is much simpler to depend entirely on the starch from the green plants and, as a result of disuse, its digestive organs degenerate so that it cannot, even if it wishes, feed like a normal animal. This is the explanation of its regular habits for in order to obtain the sunshine without which the

plants cannot form their starch, it has to expose itself to the full glare of the sun for as long as possible, that is, be exposed on the sand for the whole time the tide is out; when the tide returns it has to burrow or it would be washed away.

But, owing probably to the fact that the Convoluta needs a more varied diet than that supplied by starch, it begins after a time to feed upon the algæ—to kill the geese which laid the golden eggs—so that they gradually disappear, their owner at this stage presenting the strange appearance of an animal with a green head and a white tail. Finally, having killed its best friends, the little flatworm dies of starvation, though not before it has laid large numbers of eggs for the maintenance of the race. This may be considered a case of symbiosis which has gone too far, for, although the algæ can live freely in the sea and they are by no means dependent upon the flatworms, the latter, after originally no doubt sheltering the algæ in return for surplus food, have finally become entirely dependent, essentially parasitic, upon them, and cannot even develop if they are absent.

CHAPTER X

Sea Water

Chemistry

Sea-water is salt to the taste ; very much salter than fresh water, in which, when we drink it, we are not consciously aware that there is any salt. Yet it is, in reality, present, but in exceedingly minute quantities, for all the oceans derive their saltness from the fresh water which pours down from the land in the form of rivers.

In remote ages one can imagine that the oceans were almost fresh ; the saltness of which we are now aware is due to the accumulation of the minute quantities washed down from the land through countless centuries. It has been estimated that there is enough salt in the oceans to yield fourteen and a half times the bulk of the entire continent of Europe above high-water mark.

When sea water is evaporated down until it is dry a white crystalline substance, the sea salt, is left. Over three quarters of this salt consists of sodium chloride, the remainder being made up of small quantities of bromides, carbonates and sulphates, of sodium, potassium, calcium and magnesium.

Practically everywhere in the oceans of the world the composition of sea salt is to all intents and purposes the same, that is the proportions to one another of the different components are the same. But the actual quantity

dissolved in the water may vary from time to time and place to place for various reasons. The open ocean water, however, varies in its salinity within very small limits being almost always between 34 and 36 parts of salt to a thousand parts of water by weight. It is quite natural that in the neighbourhood of land the amount of dissolved salt is lower than in the open ocean owing to the fresh water which flows off the land diluting it.

In the Baltic Sea, for instance, the salinity of the water is very low, being always below twenty-nine parts per thousand. As we get down to the mouth of the Baltic, however, where it joins the North Sea in the Skager Rack we notice a considerable rise in the salinity due to the mingling of more saline waters coming from the North Sea itself and from water carried round by the drift of the Gulf Stream which penetrates the North Sea round the north of Scotland. Owing to its lessened salinity the stream of Baltic water is quite recognizable as it flows up past the coast of Norway.

On the other hand the salinity of sea water may be considerably higher than that of the open ocean owing to constant evaporation of the water from the surface and a consequent concentration of the salts left behind. Such conditions are to be found in the Red Sea, where the highest salinities in the world, for open waters, occur, viz. forty parts per thousand. Here, under the fearful heat of the sun, water is constantly evaporating at the sea surface and there are no rivers flowing down from the land with fresh water to dilute the sea once more. The eastern basin of the Mediterranean is also very salt compared with the open waters of the Atlantic.

(In the case of the " Dead Sea " river water has been pouring down for thousands of years into a comparatively small lake in which constant evaporation is taking place.

As a result the enormous salinity* of over 200 parts per thousand has been reached. The difference between this concentration and that of sea water is due to the very small volume of water in the "Dead Sea" compared with that of the ocean which requires almost incalculable quantities of salt to raise its salinity appreciably.)

In the Atlantic Ocean for the same reasons as those given above we find the highest salinity in the central part, the Sargasso Sea, and the lowest in polar regions where the continual precipitation of rain and snow from the atmosphere tends to dilute the surface layers.

Besides this common sea salt there are also many other substances to be found in solution. In fact there are present traces of almost all known chemical elements. This is only natural when we consider that particles of all kinds of substances must eventually be washed down from land. Amongst these many bodies silver, radium and gold are to be found. The presence of gold has of course attracted men's attention, and certain unscrupulous people have attempted to obtain capital from those who have been misled by the visions of amassing large fortunes out of sea water. Actually, however, gold is present in such minute traces that the cost of its extraction would be greater than the value of the amount obtained. The quantities present have been variously estimated and probably differ slightly from place to place. The highest value obtained is one grain of gold in one ton of sea water; that is, in order to obtain sufficient gold for that very rare coin, the sovereign, one would have to treat chemically over 100 tons of sea water.

It would be even less profitable to attempt to extract the silver, although there is evidently plenty there in bulk;

* Dead Sea Salt differs from Sea Salt in the proportions of its constituents.

for it has been estimated that there exists dissolved in the oceans 46,700 times as much silver as has been mined all over the world between 1902 and the discovery of America by Columbus, in 1492. This is, in all, 13,300 million tons, but it would be a very tedious matter to extract it !

But the most important bodies discovered in sea water are certain manurial salts which are only present in very minute quantities. These are the phosphates and the nitrates, substances which we know have a very great nutrient value in the soil on land and are among the chief components of all natural or artificial manures.

We have mentioned in a previous chapter (page 114) that in the sea, as well as on the land, all life is ultimately dependent on the plants for its supply of food. In the off-shore waters of the sea the plant life is represented almost solely by that great drifting community of plankton plants among which the minute, unicellular diatoms are the most numerous. It is on the nutrient salts present in solution in the sea that these diatoms depend for their food. On land the plant extracts phosphates and nitrates from the soil by means of its roots. The fine " root hairs " absorb the nourishing salts from the minute interstices among the soil particles where the moisture holds them in solution. In the case of diatoms, however, there is no need of any specialized structure such as the root to take up these valuable substances, for its whole body is bathed in the sea water from which the food is absorbed. More will be said in the next chapter on this subject and the effects of the presence or absence of the manurial salts on the seasonal cycle of life in the sea.

Besides these " solid " salts in the sea there are also present certain gases dissolved in the water. Animals cannot live without oxygen. We extract the oxygen that we breathe in with the air into our lungs, and it is carried

round to supply the various parts of our bodies. But in the sea we never see fish coming to the surface to take in a gulp of air as the marine mammals, such as whales, do. They have no need to do so, for oxygen is everywhere present dissolved in the surrounding water and fish have a special apparatus, the gills, for extracting it. All the larger marine animals have gills or some such specialized structure for this purpose. But in the case of the very small animals, in which the area of the body surface is very large compared with the actual volume of the body itself, oxygen can be absorbed anywhere over the surface of the body.

There is probably no part in the open sea where oxygen is not present in solution in sufficient quantity to support a large number of animals. Isolated cases are known however where there is no oxygen. Such conditions are to be found in the deeper waters of the Black Sea. Here we have a layer of light surface water down to about a hundred fathoms, below which is heavy water. The upper layers are of low salinity owing to the fresh water brought down by the Danube and other rivers, but the deeper waters have a high salinity ; hence the difference in weight of the waters. Thus there is at a certain depth a layer where the light surface water and the deep heavy water meet. This forms a kind of boundary layer between the two, and the waters above and below this depth do not mix one with another. Therefore although the oxygen supply in the upper layers may be very high, there is no means by which this gas can be transported into the deeper layers. As a result there is no oxygen below about a hundred fathoms, the only gas present being the stinking sulphuretted hydrogen. No living animals are therefore present below this depth. The only organisms that can live are certain bacteria that do not require oxygen, and

it is these bacteria that are responsible for the production of the sulphuretted hydrogen. Such a condition is unique in salt water. Even in the very greatest depths in the open ocean life is still possible. For the absence of oxygen is a result of stagnant conditions, and in the open ocean such cannot be the case owing to the continual circulation of water in the great ocean currents.

While we breathe in oxygen we send out into the air again the product resulting from its utilization, carbon dioxide. All animals are therefore constantly giving this gas out to the surrounding water and it is everywhere present. At the same time it is used up again in the upper layers by the floating plants which build up sugars out of it under the action of sunlight, restoring oxygen once more to the water.

Physical Properties

Water being the medium in which all marine animals live, there are certain of its physical properties which influence the animals themselves or tend to modify the environment under which they live. On land, for instance, the temperature of the air or the barometric pressure may induce profound changes in our bodies.

The surface temperature of the sea changes markedly from place to place. In the tropics it is hot compared with the polar regions. The highest temperature recorded in the sea is ninety-six degrees Fahrenheit in the Persian Gulf and the lowest twenty-eight degrees Fahrenheit in polar regions. Between these two limits all temperatures are to be found. Albeit this range is small compared with the great temperature differences which occur on land, the highest being one hundred and thirty-six degrees Fahrenheit and the lowest minus ninety-four degrees Fahrenheit. But although the changes are not as great

as on land, they are of great significance in the lives of the animals living in the sea. For whereas most land animals are warm-blooded and have special means for keeping the temperatures of their bodies at a constant, in the sea most animals are cold-blooded and must take up the temperature of the surrounding water. If our temperature rises only a few degrees the chemical reactions are gone through at a dangerously increased rate and give rise to fever. We can easily imagine therefore that the passage of an animal into water five or six degrees warmer than that in which it had been living may have a profound effect upon it. It is probably for this reason that the boundaries to the distribution of many animals in the sea are those of temperature. (See page 89.)

Water requires a tremendous amount of heat energy to raise its temperature; the amount of heat necessary to raise the temperature of a cubic foot of water by one degree would raise by the same amount 3,000 cubic feet of air. This is why in the summer the sea never has time to reach the high temperature of the surrounding air except sometimes just at the surface.

For the same reason water is very slow to give up its heat when once it is gained, and we notice that in winter the sea is far warmer than the air, and acts as a reservoir of heat. This explains why the climates of oceanic islands and coastal lands are much more equable than those of countries in the interior of great continents. The influence of oceanic currents upon climate is well shown by a comparison of that of the British Isles, whose shores are bathed by a branch of the Gulf Stream, with the climate of Labrador which lies in the same latitude.

At the same time any heat received at the sea surface is imperceptibly slowly conducted away into deeper layers,

and in general there is a decrease in temperature with depth. Usually the effects of the sun's warmth are not felt to a greater depth than three hundred fathoms. Actually the heat rays are rapidly absorbed by the upper few inches of water and any warmth that is transported to deeper layers is mostly brought about by the mixing of the warmer with the colder water.

Owing to this very slow warming up of the sea there is a lag in the seasonal change of temperature, and while in our latitudes the hottest time of the year is June, the water does not reach its maximum temperature until August. Now we have seen that the deeper layers only receive their heat by mixing with the warm upper water and while there is a lag between the raising of the temperature of the air and that of the water there is a further lag in the warming of the deeper water, until at about fifty fathoms we get a complete reversal of seasons. There the hottest part of the year is in December, that is mid-winter, and the coldest about May or June. Below a hundred fathoms there is no seasonal change whatever in temperature, and, year in year out, the conditions are uniform. From this depth downwards the temperature gradually falls until in the ocean abysses it remains always at somewhere near the freezing point.

The actual weight or specific gravity of the water depends on its temperature and upon its salinity, the warm water being lighter than the cool, and the fresh water lighter than salt. In the tropics therefore the high temperature makes the water light, but at the same time owing to evaporation the salinity is high, which tends to make the water heavy.

The pressure in the sea varies with the depth. At every ten metres depth the pressure is increased by one atmosphere, that is by 14 lbs. to the square inch. In the great

depths of the ocean the pressures are therefore enormous, as much as three tons to the square inch. Yet there is no part in the sea in which animals cannot live. At first sight it seems remarkable that any living creature could endure such enormous pressures, but we must realize that that is their natural environment. We, on land, live always with a pressure of 14 lbs. to the square inch on our bodies, but we are not conscious of it ; when the barometer rises by one inch the increase of pressure on our body surface may be as much as one ton, yet this is not noticeable.

The great pressures in the depths of the ocean have a slight effect on the density of the water, but because water is almost incompressible the increase in density with depth is extremely small. It can in no way be sufficient to support a persistent and erroneous popular belief that, owing to the increasing density, objects sinking will find their own level before they reach the bottom, a level in which the density of the water is the same as theirs and below which they cannot sink because the density of the water becomes greater. Sir Wyville Thomson in " The Depths of the Sea " remarks, " There was a curious popular notion, in which I well remember sharing when a boy, that, in going down, the sea water became gradually under the pressure heavier and heavier, and that all the loose things in the sea floated at different levels, according to their specific weight : skeletons of men, anchors and shot and cannon, and last of all the broad gold pieces wrecked in the loss of many a galleon on the Spanish Main ; the whole forming a kind of " false bottom " to the ocean, beneath which there lay all the depth of clear still water, which was heavier than molten gold."

It has been suggested for instance that the *Titanic* thus sank to a false bottom but under the increasing pressure sealed air chambers would become " imploded " or

smashed inwards, so that eventually there would be no air to buoy the ship up and it would be simply a mass of solid iron and wood whose combined density would far exceed that of the sea water surrounding, so that the ship would be bound to sink to the bottom. Sir John Murray said " During the *Challenger* expedition, after a funeral at sea, the bluejackets sent a deputation aft to ask if ' Bill ' would go right to the bottom when committed to the deep with a shot attached to his feet, or would he ' find his level ' and there float about for evermore ? "

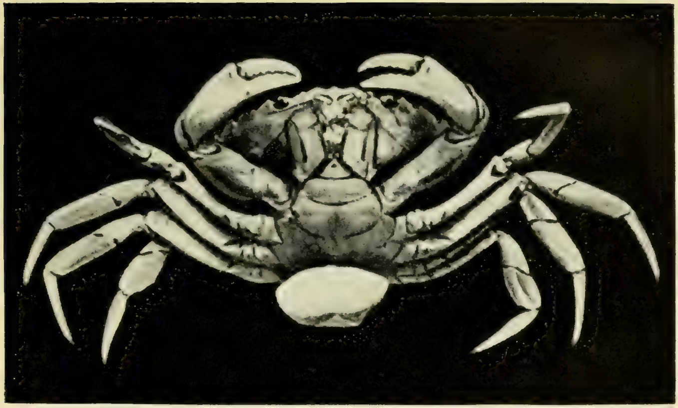
It is said that a man at 2,000 fathoms would bear on his body a weight equivalent to that of twenty locomotive engines, each with a long goods train loaded with pig iron. This was said however in 1873 when engines and trains were considerably smaller than nowadays. One of the effects of living at these great pressures is that when animals are brought up quickly in the trawl they break to pieces owing to the sudden reduction of pressure.

Most sea animals must be able to stand a considerably wide range of pressures as they are able to make large journeys up and down. Whales when harpooned have been known to " sound " as deep as four hundred fathoms. Many small animals living in the drifting community make upward journeys of fifty to a hundred metres or more almost every night of their lives retiring to the deep levels again in the daytime. In the laboratory small unicellular animals have been subjected to pressures of as much as 600 atmospheres, without suffering any apparent harm.

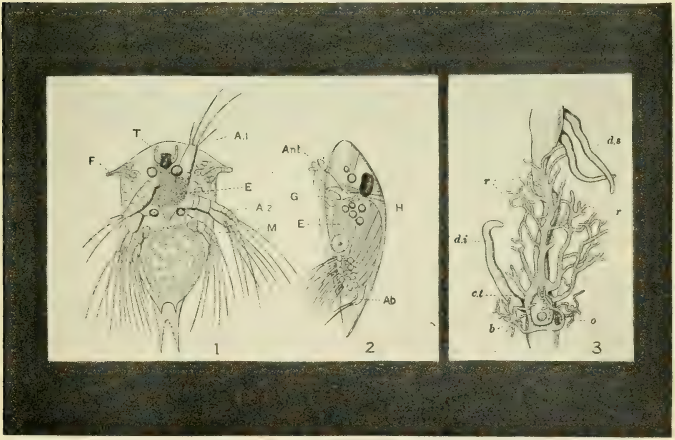
One of the most important conditions for life is light. Without light there would be no plant life, for it is by the help of the sun's rays that the plant can build up the necessary starch and sugar from the carbon dioxide in the air or in the water. Practically all animals are ultimately dependent upon plant life for their food, and if in the sea

the rays of light from the sun were cut off immediately and completely by the surface water, no plants could survive there and it is likely that our oceans would not contain that wealth of animal life in which they all abound.

The amount of light to be found at any depth in the sea depends upon the altitude and strength of the sun, on the weather conditions, and upon the amount of sand and sediment present in the water, that is to say its turbidity. Much light is reflected from the sea surface especially if there are waves, because the light rays glance off the sloping sides of the waves. It is often almost impossible to look towards the setting sun over the sea because of the dazzling path of reflected light, and we must realize that this light is not being reflected only along the path between us and the sun, but all over the sea surface, because from whatever place we look towards the sun we shall always find this path of light. The lower the sun is in the heavens the more its rays are reflected. Thus we see that it is seldom that all the light from the sun penetrates the actual sea surface ; such a thing only happens when the sun is vertically overhead and the sea itself is as calm as glass. But the rays of light that do pass through the surface cannot penetrate right to the bottom in very deep water. Out in the great oceans the darkness on the sea floor thousands of fathoms beneath the surface is absolute. This is because the light itself is absorbed by the water. But all the different colours of which white light is composed are not absorbed to an equal extent. The red rays for instance are absorbed very quickly indeed. It is a matter of several fathoms only before all the red light has gone. It is the blue and violet light that penetrates farthest and in clear ocean waters, such as are found in the Sargasso Sea, there may be violet light present at as great a depth as 550 fathoms, but its actual strength will of course be very weak. It was



A Shore Crab *(Carcinus maenas)* parasitized by *Sacculina*. Natural size. (p. 211).

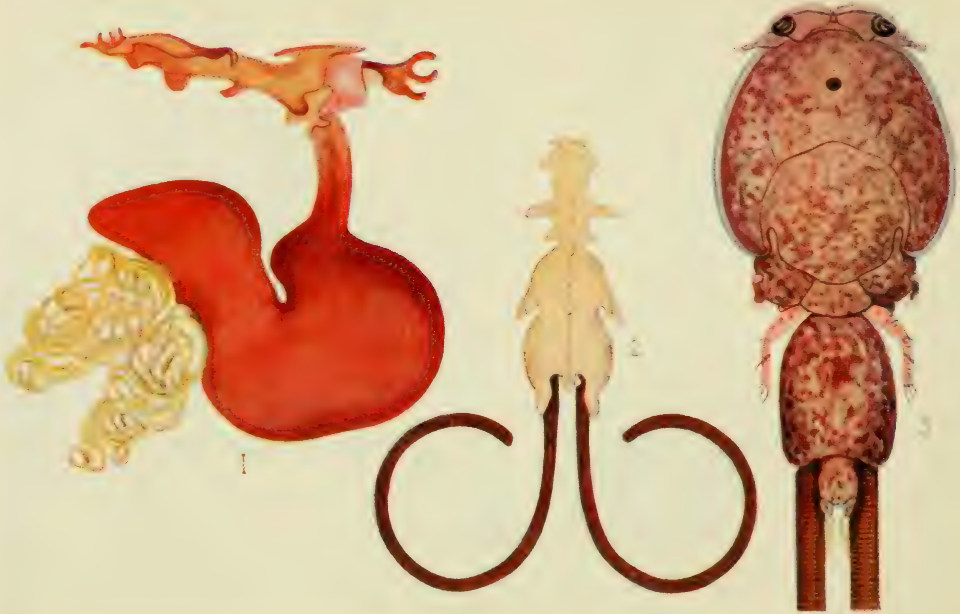


Pl. 80.

P 226.

1 & 2. Larval stages of *Sacculina*, ×35.

3. Later stage in development of *Sacculina*, showing branching of parasite over gut of crab. Natural size. (p. 211).



Pl. 81. O 227.

Crustacean Copepod Parasites of Fish. (p. 210).

1. *Lernaea lusci*, ×5. 2. *Chondracanthus lophii*, ×3. 3. *Caligus curtus*, ×6.

found that if a photographic plate was exposed for eighty minutes at a depth of 3,280 feet it was blackened by the light rays : but a plate exposed for 120 minutes at 5,578 feet was not affected (see Plate 2).

A most excellent example of the absorption of light by the sea water is furnished by the famous cave at Capri, known as the Blue Grotto of Capri. Within this cave everything is enveloped in the purest blue light. The explanation is to be found in the fact that the only light that can enter the cave itself has to pass first beneath the water which practically fills its narrow entrance. In its passage through the water much of the red light and some of the yellow and green is absorbed, and the only light that can come once more above the surface of the water to illuminate the interior of the cave is composed to a very large extent of blue rays. The blue colour of the sea also owes its origin to this phenomenon, for the colour of the water is due to the reflection of light upwards from the small particles suspended in the water itself. The light reaching a particle at a given depth is thus reflected upwards and has to pass once more through the depth of water it has already traversed in its downward journey. Much of the red and yellow light will become absorbed on this upward journey if this has not already happened on its downward passage, and it is mostly blue and green light which can survive to appear above the surface once more and give the sea its typical colour. As all these rays of light are being absorbed in their downward passage it is natural that the actual strength of the light is gradually diminishing the deeper one goes. In the open ocean the strength of light is already too weak at a depth of 100 fathoms to support much plant life (see Plate 2), and below this depth few living plankton plants are to be found. Nevertheless this upper layer of water, 100

fathoms in thickness, is sufficient to support the tremendous wealth of plant life that forms the pasturage of the sea, and it is on the rain of dead plants and organisms that have fed on them that the animals in the dark ocean depths depend for their food. It is hard for us to realize what the actual strength of the light is at different depths in the sea. Not enough accurate work has as yet been done for us to be able to make actual comparisons; but it has recently been shown at Plymouth that in the open waters of the English Channel the light at a depth of about sixty feet corresponds to that found in the heart of an English beech wood, and this is quite dim. At such a depth in the Mediterranean however the light would be very much stronger, not only because the sun itself is so much more powerful, but because the water is clear and lacks that sediment of sand and mud that so discolours the water in the English Channel.

Currents

The great oceans of the world are not merely masses of stationary water. There exists within them a system of gigantic currents whereby the water is continually circulating and moving from place to place.

Amongst these currents is that known as the "Gulf Stream," a name familiar to all on account of its bearing on the climate of our islands. In order to understand roughly how the Gulf Stream takes its being and how it moves, it is necessary to consider the whole of the North Atlantic ocean. The Gulf Stream is a great oceanic current that receives its name from its place of origin, the Gulf of Mexico, whence it issues through the Straits of Florida as a stupendous river of warm blue water fifty miles in width and three hundred and fifty fathoms deep.

The forces that set and keep this great mass of water in

motion are varied, and among these the polar ice, the sun's heat, the trade winds and the rotation of the earth all play their part.

This current is really only a portion of a system of currents in continuous circulation in the Atlantic Ocean, a system which cannot be said strictly to begin or end anywhere. We will however confine ourselves here to the North Atlantic.

In the region just north of the equator the surface waters are warmed by the fierce heat of the tropical sun and their salinity is raised by constant evaporation. Upon these warm saline waters are continually blowing those persistent north-easterly winds known as the "North-east Trades." Their action aids a natural tendency of the surface waters to move in an easterly direction towards the north coast of the South American continent as the North Equatorial Drift, which flows on into the Caribbean Sea and Gulf of Mexico. Here the waters become piled up so that the surface level is raised above that of the ocean water outside the islands of the West Indies in the Sargasso Sea. Under such conditions the water must flow somewhere in order to maintain its equilibrium. Its only place of egress is through the Florida Straits and here it issues as the mighty Gulf Stream, the actual current through the straits being sometimes known as the Florida Stream. From here the Gulf Stream runs in a northerly direction along the coast of America at a speed of about four knots (Plate 85).

Owing to the rotation of the earth there is a tendency for any moving particle to be deflected to the right. This action is felt by the Gulf Stream and it moves northwards with an increasing trend towards the right or east, so that by the time it has reached latitude forty degrees north it is flowing due east across the Atlantic. At this point

it has lost a certain amount of its speed and has widened out considerably. At the same time, coming into less heated climes, it has cooled down to a certain extent.

Just near the Labrador coast however a potent force comes into play. Here are vast masses of drifting ice floating down from polar seas on the cold Labrador currents. These ice floes meet the warmer water and cool it. Cooled water is heavier than warm water and must therefore sink, and as it sinks it is replaced by more warm water near the surface (Fig. 47). This process continues while the ice is melting, so that it, so to speak, attracts the warm waters to it, asking for destruction. The mass of all the

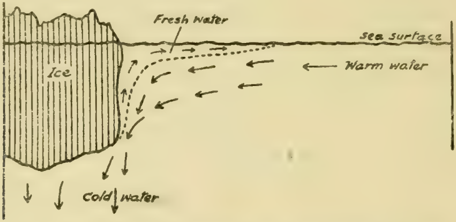
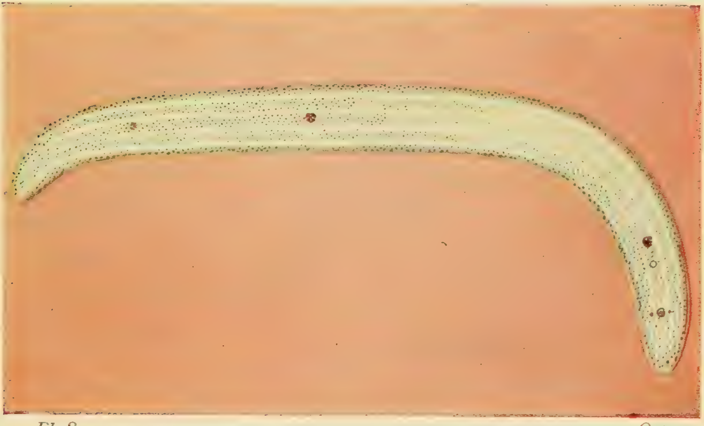


Fig. 47.—Diagram showing the movements of the surrounding water caused by melting ice.

ice in this region thus exerts a considerable power and deflects a part of the Gulf Stream which splits off from the east-going current and moves up north over the Newfoundland Bank and on to the Norwegian Sea.

The remaining east-going stream continues on across the Atlantic ; part, owing to the earth's rotation, still bears to the right until eventually it returns to its place of origin in equatorial waters, thus completing a circle. The remainder, sucked North to replace water moving South from polar regions and aided by prevalent south-westerly winds, moves on towards the British coasts as the North

Green patches of *Convoluta roscoffensis* on beach. (p. 214).



Pl. 82. Q 230.

Convoluta roscoffensis, a flat-worm with symbiotic green algae, ×35. (p. 214).

Photo. Underwood Press

Swell waves. (p. 240).

Photo. Underwood Press

Pl. 83.

Waves breaking on shore. (p. 239).

() 231.

Atlantic Drift. Still bearing to the right it bathes the coasts of Ireland and then the western coasts of Scotland. Passing the north of Scotland it meets again that portion which had been deflected near the Labrador coasts and the two carry on together to the north of Norway, a small branch turning south into the North Sea.

On reaching Arctic regions this originally warm surface water has been cooled down nearly to freezing point. It has however still a larger salt content than the water over which it has been flowing, and is therefore heavier at the same temperature. It therefore sinks, and then creeps slowly back towards the equator as a deep bottom current which rises once more just north of the equator to replace the water that is being driven westwards on the surface by the trade winds.

Such in simple outline are the main features of the oceanic circulation in the North Atlantic. In the South Atlantic a slightly different circulation exists on account of the configuration of the land masses; and the two systems become linked up in the region of the South and North Equatorial Drifts.

In the Pacific, too, there is a system of oceanic currents much after the manner of that in the Atlantic, the Japan Current or "Kuro Shiwo" corresponding to our Gulf Stream.

In these great circulations there are to be distinguished two types of water movement, the "drifts," and the "currents" or "streams."

The drifts are brought about by wind action, and are horizontal movements of the surface waters more or less in the same direction as the wind is blowing. Currents on the other hand are translocations of bodies of water caused by a definite head of water. In the Gulf of Mexico such a head of water is produced in the manner mentioned above

(page 229) with a result that a current flows out through the Straits of Florida, the Gulf " Stream." On reaching more northern latitudes, however, the driving force on the Gulf Stream ceases to be a difference in water level, but it is now sucked in towards the ice in polar regions and considerably aided by persistent South-West winds which drift the surface water along in a North-Easterly direction, so that the waters that bathe our coasts are more correctly termed those of the North Atlantic " Drift " than the Gulf Stream.

These types of water movement, drifts and currents, are to be found always around our coasts. There is for instance a prevalent drift of surface water up the English Channel and through the Straits of Dover into the North Sea. In fact " drift bottles " (i.e. special bottles used for measuring water movements [see page 257]) liberated in the western end of the English Channel have been known to travel in the surface drift on to the Swedish and Norwegian coasts in just over a hundred days, a distance of about 700 miles. One indeed was picked up on the north shore of Norway after having travelled a distance of 1,440 miles at a speed of about 7·6 miles a day. In these instances, however, there was no actual movement of water mass at anything approaching this speed.

When a strong wind has been blowing for some days on to the shore, the surface water then becomes piled up on the shore on which the wind is blowing with the result that a head of water is produced and water flows outwards in the deeper layers to replace the water that has been driven in by the wind (Fig. 48).

There remains one other type of water movement, and this is movement of bodies of water in a vertical direction, either upwelling or sinking. Sinking water masses are produced in various ways, such as in the case of water of a

uniform salinity cooling in its surface layers, when the density of this surface water increases and it sinks downwards. Upwelling of water occurs when a deep current meets a submerged bank or the shelving bottom of coastal regions: it can also be brought about by persistent off-shore winds, which blow the surface water outwards and this is replaced by water from below (Fig. 48). The upwelling of water is of the greatest importance, for the deep waters of the sea abound in those nutrient salts, the phosphates and nitrates, and when water from deeper levels rises to the surface it brings with it this store of nutriment to replenish the impoverished surface waters (see page 246). This is why, in the region of submerged shelves and in coastal areas, life is so abundant.

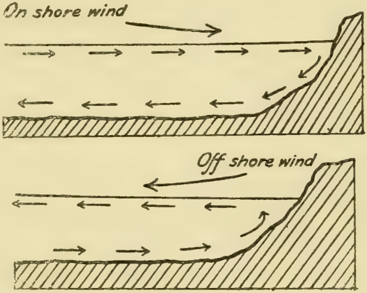


Fig. 48.—Diagrams to show the currents set up by on- and off-shore winds.

Tides

Apart from these great circulatory currents in the ocean there are other periodic movements brought about by the attraction of the sun and moon on the waters. These are the tides.

The mass of the moon exerts an attracting force on the particles on the earth. This force is greater on those particles which lie closest to the moon, but it is extremely small, being only one ten-millionth of the earth's pull on those same particles. Let us imagine the earth to be stationary and covered uniformly all over with water. The pull of the moon on the water immediately beneath

it is so small as to have no effect in drawing it vertically away from the earth's surface. But the further we go from this point on the hemisphere directed towards the moon the more horizontal does the moon's pull become. It does not take nearly so great a force to make water slide horizontally over the earth as to draw it vertically upward, and the moon's attraction is sufficient to do the former. The result is that water is drawn over the surface of the earth from all around and towards the point beneath the moon so that the water becomes piled up there. Where this bulge of water occurs the tide is high.

On the hemisphere of the earth pointing away from the moon exactly similar forces are acting to cause high tide at the point furthest from the moon. How these forces come about can be proved mathematically, but it is somewhat beyond the scope of this book to enter into an explanation.

In this way there are two high tides simultaneously on the earth, one at a point beneath the moon, and the other on the other face of the earth opposite to the first. These two high tides cause the water lying between them to be drawn away, so that at two points lying on either side of the earth midway between the two high tide regions there will be low tides.

But the earth is revolving, so that approximately once each day the moon exerts its influence on every meridian on the earth's surface in turn. Under these conditions the points at which high tide occurs change with the changing position of the moon, and a " tidal wave" sweeps round the surface of the globe. (This must not be confused with the popular and wrongly named " tidal wave " of great dimensions and destructive force, which is usually a wave caused by a submarine earthquake and quite unconnected with the moon's attraction.) If the earth

were covered uniformly with water down to a depth of fifty-three miles the speed of this wave around its surface would be about 1,000 miles an hour. Owing to the comparative shallowness of our oceans however it has only about half this speed.

The surface of our earth is not uniformly covered with water, but possesses great land masses which jut out into the ocean and tend to complicate the results of these tidal forces so that a truly satisfactory theory of the tides has not yet been evolved. It is however safe to say that the primary cause is that given above.

The only region on the earth where the ocean forms a continuous band around the globe, uninterrupted by land masses, is in the southern ocean and there is a theory that around this belt sweeps the great tidal wave, a "primary wave." This wave is supposed to give off secondary, or "derived waves," which move in a northerly direction up the other oceans. Such a wave moves up the Atlantic Ocean at a speed of about 500 miles an hour (Fig. 49). In the open ocean the wave is only two or three feet in height, so that the tides in oceanic islands are very small. But as the water shallows round the edge of the ocean the speed of the tidal wave is enormously reduced by friction and the height of the tides becomes greater. Thus the height of the tide at the Azores is about five feet, that around the Scilly Isles sixteen feet, and that at Swansea twenty-seven feet. As the tide runs up narrow channels the water tends to be bottled up and therefore the highest tides are found in such channels as the mouth of the Severn, where the tide may reach nearly as much as fifty feet at Chepstow.

There are produced around our coasts two high tides in the twenty-four hours and two low tides, but owing to the fact that the moon is also moving round the earth the

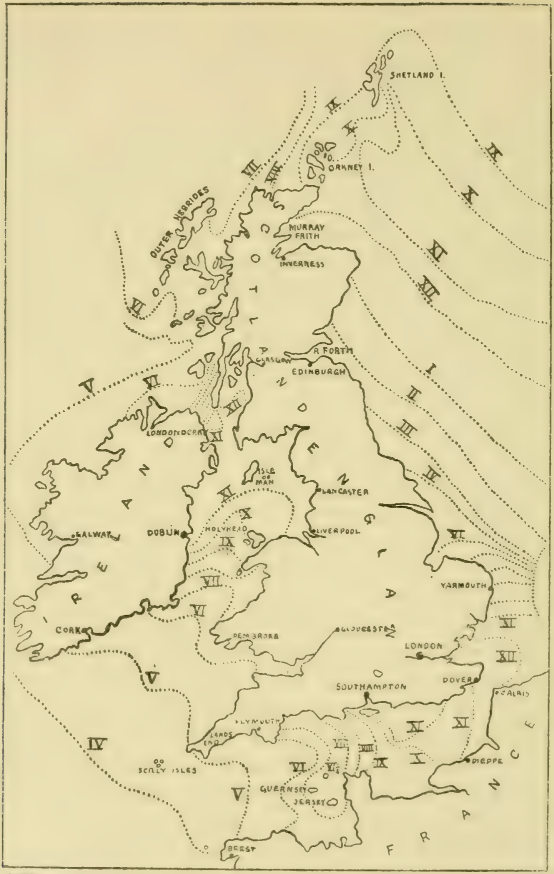


FIG. 49.—Map showing the progress of the tidal wave round the shores of the British Isles. The Roman numerals indicate the times of high water as the wave moves along the coast.

interval between one high tide and the next is not exactly twelve hours, but on the average twelve hours and twenty minutes. Thus the time of high water is not the same every day, but there is a progressive change, the high tide of to-morrow afternoon being about forty minutes later than that of this afternoon. So throughout the years there is practically no time of day at which high or low water may not occur at any place.

Together with this change in the time of the tides there is also to be noticed a change in the actual range of the tides, the distance between high and low-water marks becoming progressively greater throughout a certain period and then correspondingly smaller. These periods are known as the periods of " spring " and of " neap " tides.

During the " spring " tides (Saxon: *sprungen*, " to bulge ") the low-water mark is lowest and the high-water mark highest, that is, the range between the tide marks is greatest; during the neaps the reverse is the case, the tide only coming in and going out a short distance. Besides the attraction of the moon there is also a smaller attraction exerted by the sun. It is because of the sun's attraction that the spring and neap tides are caused. When the sun and moon are both exerting their pulls in the same direction the force will be at its greatest and the big tides or springs will occur. This happens shortly after both new and full moon (Fig. 50). But the range of the tides will be greatest at new moon, because then the sun and moon are both on the same side of the earth; and the spring tides are less at full moon, the sun and moon being then opposite one another. When the forces of the sun and moon are at right angles to one another, i.e. at the periods of half moon, the range of the tides will be least and neap tides will result.

The tides must not be confused with " tidal streams "

which are the horizontal currents moving the water which forms the progressing tidal wave. In the open oceans the wave, as already mentioned, is only a foot or so high, so that the tidal stream is imperceptible ; but near the coasts where the tidal wave increases in height the tidal stream may be considerable.

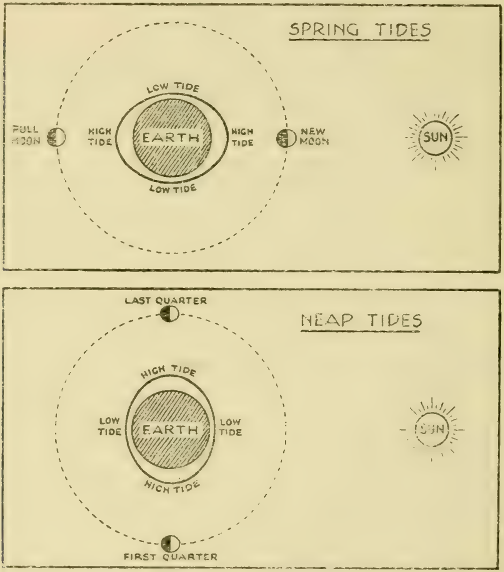


Fig. 50.—Diagram illustrating the action of sun and moon in causing spring and neap tides.

Waves

Waves are an integral part of the sea. It is rarely, if ever, the case that the sea is so calm that there is not the slightest ripple, or failing that a long low swell, the after-

Photo. Topical Press

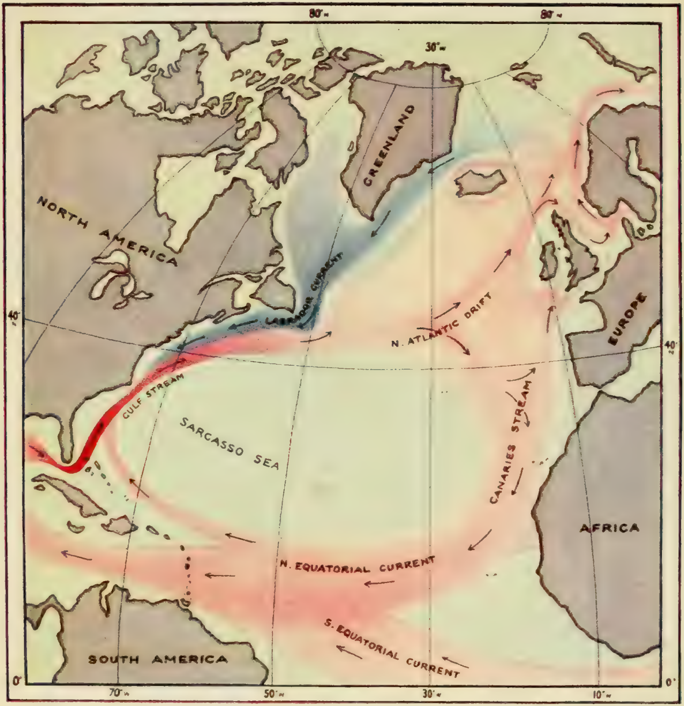
Pack Ice. (p. 241).

Photo. H. G. Ponting

Pl. 84.

Q 238.

Floe Ice. (p. 241).



Pl. 85. Q 239.

Surface Currents in North Atlantic. (p. 229).

Red, warm currents. Blue, cold currents.

math of a heavy storm or the herald of wind to come. Waves are of great importance in helping to keep the surface waters of the sea mixed, while in the tidal zone they have left their mark in the many adaptations shown by littoral animals for protection against the pounding surf.

Waves are generally the result of the action of wind on the sea surface, from the faintest ripple caused by the light airs of summer to the tumultuous mountains of water raised by the full force of a winter's gale (Plate 83). The size of the wave depends upon the strength of the wind and upon the distance through which the wind can act. In open waters in mid-ocean, therefore, the largest waves occur, because there the space is greatest; and of ocean waters those of the southern ocean have greatest expanse and exposure to gales, and it is there that the waves reach their greatest height. The height of a wave is the vertical distance between the summit of the crest and the deepest point of the trough. The maximum height of waves recorded by measurement are for the Mediterranean seventeen feet, the Bay of Biscay twenty-seven feet, the Atlantic Ocean forty feet, and the Pacific Ocean off the Cape of Good Hope fifty to sixty feet.

The speed at which a storm wave travels in the Atlantic Ocean is about twenty-two miles an hour, while off Cape Horn as much as twenty-seven miles an hour has been recorded.

The wave in the open ocean is of the type known as an oscillatory wave. That is, while an undulation passes through the water, after the wave has passed, the water particles are still where they were and have not received any movement in a horizontal direction. Actually the movement of the water particles is a circular one, backward and upward on the lower half of the wave front, then forward and upward to the summit of the crest, forward and down-

ward for the upper half of the back of the wave, and then backward and down to the hollow of the trough (see Fig. 51). When these oscillatory waves approach the shallow water of the coast their shape changes. They become shorter and higher and the advancing front of the wave steepens and the water particles now have a forward motion. Eventually it becomes so steep and top-heavy in front that it topples over in a mass of seething foam to form a breaker and adds to the grandeur of the surf. When the wind is off-shore water is blown off the top of the breaking crest in the form of spray.

There may be waves present, but no wind. Such waves are known as "swell," and they are waves that have

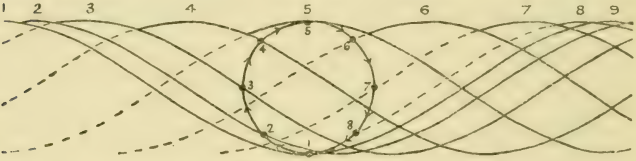


Fig. 51.—Diagram illustrating the movement of a particle on the sea surface caused by the passage of a wave. 1, 2, 3, etc., are the successive positions of the wave crest and of a particle on the sea surface at the same time.

travelled beyond the windswept area or have been left on the face of the troubled ocean after a storm has passed (Plate 83). A combination of swell and wind-waves can often be seen.

There are, besides, the so-called "tidal waves," the products of land or submarine earthquakes. These may be waves of very large dimensions produced by an earthquake on the sea floor; or, when an earthquake occurs in coastal regions, the sea may recede far beyond the normal low-tide mark and then hurl itself with relentless fury back on to the land, bringing death and destruction with it.

Ice

In the polar regions the surface of the sea is frozen. When the surface water freezes it does not usually attain a greater thickness than seven feet in a year. When first formed it is known as " floe ice " (Plate 84). Cracks in the ice, widening into lanes, cause the separation of the ice into floes which drift at the mercy of wind and current. Under certain conditions these floes become driven together and under the great pressure they become packed together to form a mass with uneven surface, floes becoming tilted up on end and forced half out of the water, the whole presenting an appearance of jumble and disorder. Such ice is known as " pack ice " (Plate 84).

In the open ocean, often far from polar regions, " icebergs " are met with (Plate 86). These are in no way connected with the floe or pack ice, but are derived from glaciers. The majority of those met with in the North Atlantic come from the great glaciers of Greenland. These solid rivers of ice flow slowly into the sea, where partly by wave action, and partly by uneven adjustments of weight, great masses break off to form the icebergs. The actual process of breaking off is known as the " calving of an iceberg."

These castles of ice, often fantastic in shape, float down into the Atlantic on the Labrador Current, a menace to passing shipping. Only a small portion of the mass of ice is visible above water, as it floats with almost eight-ninths submerged.

Recently a new method has been tried for destroying these floating perils. A boring is made into the side of the berg and a charge of " thermite " inserted, which, on ignition, gives off an intense heat. After several hours the berg breaks up owing to the uneven stresses and strains set up

by the temperature changes occurring in its interior after the explosion, the cracking of the berg into pieces sounding like a series of gun reports.

Since the tragic sinking of the *Titanic* by an iceberg, an Ice Patrol Service is on constant duty to give warning to passing ships of the presence of the bergs and to study their drift and movements.

Curiously enough one of the first signs of an approaching iceberg is a rise in the temperature of the water. The surrounding sea water on bathing the ice becomes cooled and hence heavier, and sinks, and more warm water flows in to take its place. But the fresh water from the melting of the exposed part of the berg pours down off its sides into the sea. Owing to its freshness it is considerably lighter than the sea water and floats at the surface. Similarly water from the ice melting below the sea surface rises. Fresh water heats up more readily than salt water, so that this lake of fresh water which surrounds the iceberg on all sides gains more heat from the sun than the sea water (Fig. 47).

CHAPTER XI

Ocean Seasons

One of the most obvious phenomena on land in our climes is the rotation of the seasons. If we were suddenly let loose from a prison in which for many years we had lost count of time, and if our course were then directed to a country garden, a wooded valley or a mountain marsh, we could read at a glance by the presence of flowers, birds or insects the season of the year. We can follow this endless daily change in our gardens, in the woods, and in ponds, but to many the seasons of the sea are a closed book, save for the changes to be seen in that narrow fringe around our shores, the tidal zone.

It is for this reason that the subject is given a chapter to itself, to emphasize the fact that there are seasons in the ocean, and that in the causes of the seasonal changes lie some of the most fascinating problems of marine research.

Perhaps nowhere can the signs of the seasons be more clearly read than in that drifting community of plant and animal life known as the plankton. Anyone who takes collections with the tow net at regular intervals of time in the waters off our coasts will be struck at once by the unexpected suddenness with which the composition of the catches may change from week to week. He will see, as it were, an ever changing panorama of life.

In the early months of the year, March and April, when the sun is climbing in the heavens and its light increasing in strength, we note a very great change in the plankton

from that of the previous months. Under the influence of the benevolent rays of the sun, the tiny floating plants, the diatoms, thrive and multiply exceedingly. Each single-celled plant divides in half within the space of a day, the two cells thus formed reproduce in turn to give rise to four, so that in the course of a week or a fortnight their numbers have risen prodigiously. If we draw our tow net through the waters of the sea in spring we find that its meshes become clogged with these little diatoms, and, although singly almost invisible to the naked eye, they now tinge the surface of the net green, so countless are their numbers. Then indeed is the pasturage of the sea most rich.

Just about this time too there is a veritable outburst of animal life in the plankton. In the early months of the year a great number of all kinds of animals start to breed. As we have already mentioned, there are few animals around our shores whose early days are not spent drifting freely in the water layers. The presence of these temporary members of the plankton becomes very noticeable in April, when a tow net catch will be found to consist almost exclusively of these babies of the sea. There will be larval stages of starfish, molluscs, worms and crustacea (Plate 87). Close around the rocks are amazing swarms of the minute free-swimming young of the acorn-barnacle which covers the surface of the rocks between tide marks (Plate 87). Now is their time to enjoy a free life, for within a month, they will have fastened themselves to the rocks by their heads, there to remain kicking food into their mouths with their feathery legs until they die. Further from the shore, stretching over mile upon mile of water are the young of that ubiquitous plankton copepod, the Calanus, and mingled with them are the young of countless other closely allied but smaller species. Young fish, too,

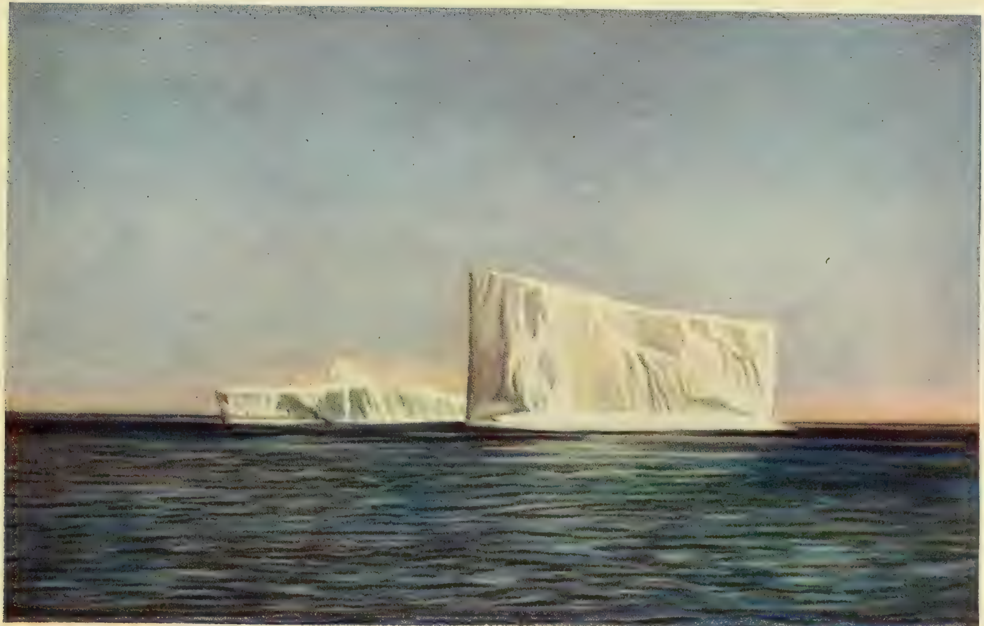
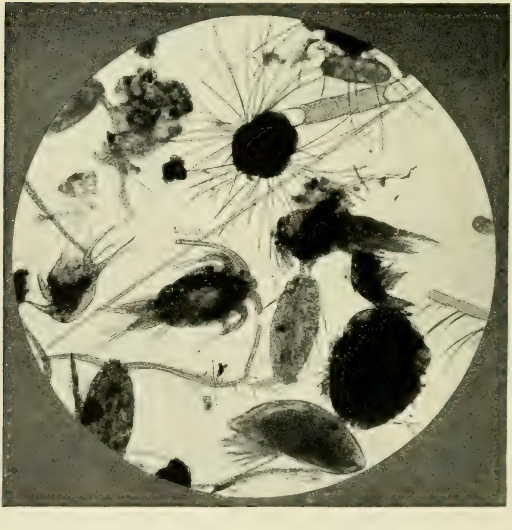


Photo. Underwood Press

Pl. 86.

Iceberg. (p. 241).

Larvae of Acorn-barnacle *(Balanus)*. ×11. (p. 244).



Pl. 87. *P.* 245.

Plankton containing larval crustacea and worms, ×44. (p. 244).

now become abundant. All these are born in time to partake of the rich pasturage drifting in the sea. The most minute of the animals will feed directly upon the diatoms, and in their turn will fall a prey to their own larger enemies.

By May or June the great crop of drifting plants is considerably diminished ; much of it has been eaten, but a large quantity also has sunk to the sea floor where it forms food for the large population of minute animals living in the muddy layers just above the bottom. This plant community, or phytoplankton as it is called, gives place in the summer months to a community of animals, the zooplankton, forms which are now growing up and feeding one upon another. Throughout the summer the appearance of this population is always changing, new forms being set free into the water by their parents and others disappearing to take up their abode on the sea bottom.

So the succession of life passes on until in the autumn, about October, there is another somewhat surprising outburst of plant life, yet never so great as that of the spring. Soon after this the plankton rapidly dies down, until in the winter it is at its poorest, only a small number of animals surviving to tide over the lean months and give rise once more to their numberless progeny in the following spring when the sea wakes up from its winter sleep.

One of the most interesting problems in marine research has been the search for the causes of this succession of life in the sea, and it is only in quite recent years that the underlying principle has been brought to light. It is evident that on the quantity of plant life present depends the number of animals that can exist, and that therefore the great changes in wealth of animal life can be traced to the increase or decrease of plants. The countless animals

which reach maturity during the course of the summer months do so at the expense of the great flowering of drifting plants that occurred in the spring. These for some reason die down in the summer, to be followed by a smaller and shorter outburst in the autumn. To explain these seasonal changes we must go back still further, and find the causes for these curious maxima of plant abundance.

It is common knowledge that to obtain good crops on land we must manure the ground ; of first importance in manure for plant growth are those chemical bodies, the phosphates and nitrates. Sea water contains these in minute quantities in solution. At the beginning of March, and indeed throughout the previous winter months, these salts are present in greatest quantities, but it is not until the spring that the diatoms are able to utilize this manure to any great extent ; for plants are dependent for their activities upon light, and during the winter the sun's rays are very feeble, and owing to the sun's low altitude little of its light penetrates into the water and much is reflected from the surface. In the spring months however the sun mounts in the sky and its light increases in strength. The sun's energy now becomes available for the plants' activities and they start to grow. With the large available fund of manurial salts the growth is rapid ; but the food supply is not inexhaustible and within a month it is almost all used up (Fig. 52) and the great crop perforce dies down. Throughout the summer months there may be very small sporadic outbursts of plant life where the water has perhaps been temporarily enriched in nutrient material by the presence of large shoals of animals whose excreta manure the surrounding water, but the renewed vigour of the diatoms in the autumn still remains to be explained. The cause of this has been found to lie in the physical properties of the sea water. During the hot summer

months the surface waters become warmed and we have seen on page 222 that owing to the bad conductivity of the water this heat is only very slowly dissipated into the deeper layers. The result is that a layer is formed at the surface with a temperature two or three degrees higher than that of the water beneath. Between these two water masses there is a very narrow layer in which the temperature changes very abruptly from that of the upper water mass to that of the lower. This is known as the "discontinuity layer" and owing to certain physical properties of water it becomes extremely difficult for the upper and lower water masses to mix one with another, thus forming an almost impenetrable boundary, and only under the action of very severe gales can it be broken down. The depth at which the layer is formed becomes deeper as the summer advances, but never gets much below twenty metres.

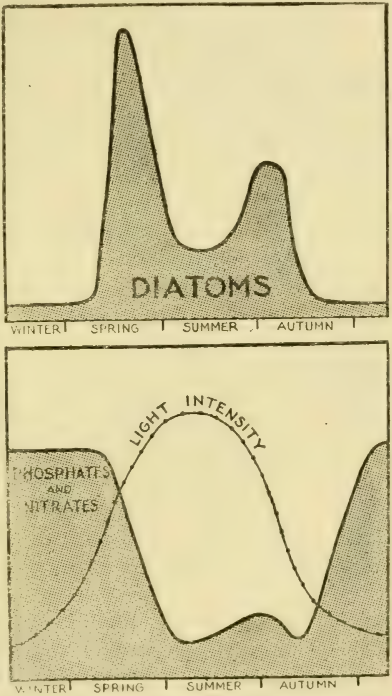


FIG. 52.—Diagram to show the relation between the number of diatoms and the amount of phosphates and nitrates in solution in the sea in temperate regions during the year.

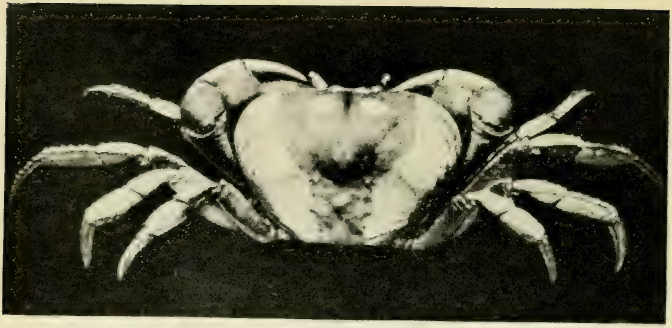
As a result of the formation of this discontinuity layer we find the clue to the poor plant-life during the summer giving rise to a fresh outburst in the autumn. For while all the nutrient salts have become used up in the surface layers a fresh supply is being formed in the deeper layers from the sinking down of dead and dying animals and from other organic remains. But owing to the inability of the upper and lower layers to mix, this supply of food substance is completely cut off from those plants living in the surface waters above the discontinuity layer where the light conditions are best for growth. In the autumn, when the surface layers begin to cool down, the waters become once more of the same temperature from top to bottom. All the water masses can now be mixed and this is soon brought about by the autumnal gales. As a result fresh supplies are brought up into the surface layers where there is still sufficient light for the plants to grow actively and a renewed flowering of the diatoms takes place. Soon, however, with the onset of winter, the sun's light becomes too weak and the plants die down until they are wakened once more into life in the following spring.

From the changes in the amount of phosphates in the waters of the English Channel, off Plymouth, a minimum estimate has been made of the actual extent of this diatom crop during the year. Assuming a depth of thirty-eight fathoms the minimum annual yield of diatoms would be as much as five and a half tons (wet weight) in the water layers lying beneath one acre of the surface. It is interesting to compare this with the quantity of crops obtained on land. For instance, between the years 1895 to 1904 the average annual yield of potatoes was 4·84 tons per acre, the highest value for any one year being 5·81 tons. Over the same period that for turnips and swedes was 13·21 tons per acre.

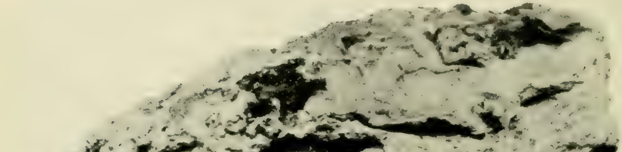
Pl. 88. DEL. M.V.L. *R* 248.

Diatoms, all greatly enlarged. (pp. 113, 132, 244).

1. *Coscinodiscus excentricus.* **2.** *Skeletonema costatum.* **3.** *Chaetoceros curvisetus.* **4.** *Rhizosolenia styliformis.* **5.** *Lauderia borealis.* **6.** *Biddulphia mobiliensis.* **7.** *Eucampia zoodiacus.* **8.** *Nitzschia closterium.* **9.** *Corethron criophilum.* **10.** *Thalassiosira gravidis.*



A Land Crab *(Gecarcinus)*, reduced. (p. 251).



Pl. 89. *R* 249.

Holes of Palolo worm in Coral Rock. Natural size. (p. 250).

These seasonal changes in the quantity of plankton are reflected in the growth of all the larger animals in the sea. A very great number of the small invertebrates living on the sea floor might be termed annuals. Spending their early life in the drifting plankton community in the spring, they soon settle to the bottom and reach maturity in the course of the summer. The countless young that never survive to maturity have nourished other growing animals, which in turn have fallen prey to the larger creatures. It is probably largely for this reason that we find that most of the fish in our northern waters make the greater part of their growth during the summer. Plankton is then present in greatest quantity for those pelagic fish such as the herring and the mackerel which feed directly on it. Then, too, at its greatest is the toll of life among the young molluscs and crustacea at the hands of such bottom-living fish as the plaice. It is natural that during the period of greatest feeding most growth takes place and this is shown very distinctly on the scales of many fish. A reliable index to the age of these fishes is afforded by the number of wide and narrow zones shown on their scales, the wide zones corresponding to the period of greatest growth which generally takes place in the summer, and the narrow zones to the period of poor growth in the winter.

Such then is the cycle of life in our northern seas. But it remains to be discovered how the animal and plant life in the tropical waters varies with the time of year. Here there are not the marked temperature changes that occur in temperate seas neither does the strength of the sun's light vary to such a marked extent. At any rate it is probable that at all periods of the year it is sufficiently strong to allow active growth amongst the drifting plants. On account of this uniformity in temperature and light it is thought that such marked changes in the

rotation of life as are exhibited in our waters are absent. In many parts of the world, however, there are dry and rainy periods, monsoons, and other weather conditions that alternate with unfailing regularity during the year and it is more than probable that these secular changes may have their effect upon the life in the sea.

There are at any rate in tropical, as well as temperate, waters animals which, if not giving an index of the season of the year, show without fail, by their spawning habits, the times of the lunar months. It is quite a common occurrence to find that marine animals will breed at certain fixed stages of the moon. It has been shown that our common oyster has a tendency to "spat" in much greater numbers during the week following the full and new moon than at any other time. In Egyptian waters also there is a sea urchin that breeds during the nights when the moon is full. But perhaps one of the most surprising cases of this kind is supplied by a small marine worm from the tropical seas near Samoa in the Pacific Ocean, the "Palolo Worm" (*Eunice viridis*). This worm can be regarded as a veritable sea calendar. All the year round it lives in holes and crevices among rocks and coral growth on the sea bottom (Plate 89). But true to the very day, each year the worms come to the surface of the sea in vast swarms for their wedding dance. This occurs at dawn just for two days in each of the months, October and November, the day before, and the day on which the moon is in its last quarter; the worms are most numerous on the second day, when the surface of the ocean appears covered with them. Actually it is not the whole worm that joins in the spawning swarm. The hinder portion of the worm becomes specially modified to carry the sexual products. On the morning of the great day each worm creeps backwards out of its burrow, and when the modified half is

fully protruded it breaks off and wriggles to the surface, while the head end of the worm shrinks back into its hole. The worms are several inches in length, the males being light brown and ochre in colour and the females greyish indigo and green. At the time of spawning the sea becomes discoloured all around by the countless floating eggs.

The natives are always ready for the spawning swarms as they relish the worms as food. They catch them by dipping them up in special baskets and so greatly do they esteem them that the native chiefs send them as presents to those living inland. The worms are eaten either cooked and wrapt up in bread-fruit leaves, or quite un-dressed. When cooked they are said to resemble spinach, and taste and smell not unlike fresh fish's roe.

From remote antiquity it has evidently been the custom of the natives to watch for them, for the natives of Fiji, who call them " Mbalolo," have incorporated them in their calendars. They call the parts of the year corresponding to the October and November swarming periods " Mbalolo lailai " (little) and " Mbalolo levu " (large), the November swarms being the greater of the two.

The natives first note the approach of the season by the appearance of the scarlet flowers of the " Aloalo " (*Erythrina indica*). They watch for the flowering of other plants until the " Seasea " (*Eugenia*) is in bloom. Then they look for the moon being just on the horizon at the dawn of day, and on the tenth morning the Palolo worms appear. However, sometimes the extra lunar month throws out their calculations.

In Savaii the approach of the Palolo is heralded three days beforehand by the appearance of the " Malio " or land crabs (*Gecarcinus*) which march down from the mountains to the sea in swarms (Plate 89).

The natives of the Gilbert Isles say that the Palolo is a

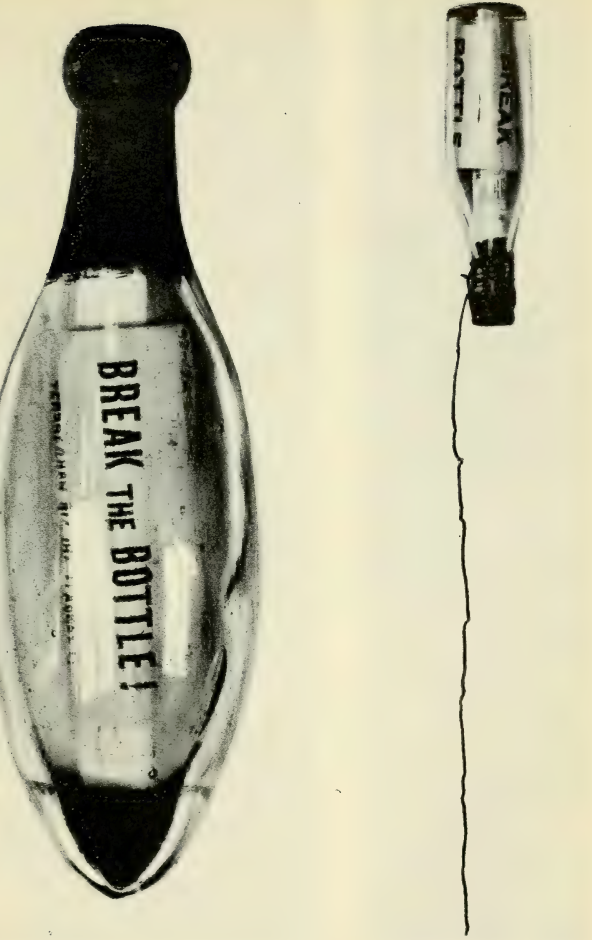
production of the coral, growing out of it, and they call it "Nmatamata" or the "Glistener"; it appears in that locality in June and July.

There is also a closely allied form, the Atlantic Palolo (*Eunice fucata*) (Plate 93), whose habits are very similar. The swarms of this worm have been studied for nine years at Tortugas and they always appeared within three days of the time of the moon's last quarter between June 29th and July 28th. The sexual portions begin to rise to the surface at least two hours before sunrise; by sunrise they are present in countless numbers and when the first rays of the sun strike the water they break up and discharge the eggs. The dying bodies sink to the bottom where they are eagerly devoured by waiting fish and by three hours after sunrise none are to be seen.

At Amboina in the Malay Archipelago there is a similar worm, the "Wawo," which swarms on the second and third nights after the full moon of March and April.

The Japanese can also boast a Palolo; they call it "Bachi" (*Ceratocephale osawai*). In this case it is the front end of the worm which becomes modified and breaks off. The swarming occurs during the nights immediately after new and full moon in October and November and the fishermen catch them by means of lights to which the worms are attracted; they use them then as bait.

It is hard to understand what can be the cause of these curious phenomena. It has been thought that the stimulus for spawning might be found in the state of the tides. Experiments have shown however, that probably the tide can have no influence, for worms placed in floating tanks spawn naturally at the usual times, and in this case the worms could have had no means of telling the state of tide either by the pressure of the water or the speed of its movement.



Pl. 90. *R* 252.

Drift Bottles. (p. 257).

Surface bottle, $\times\frac{1}{2}$.

Bottom trailer, with wire to keep bottle off bottom, $\times\frac{1}{6}$.

Pl. 91. DEL. F.S.R. *R* 253.

Larval Stages in Plankton (pp. 122, 241).

1. Larva of Porcelain Crab (*Porcellana*) × 12.
2. Larva of Hermit Crab (*Eupagurus*). × 12.
3. Larva of Squat-Lobster (*Galathea*), × 12.
4. Shell of larval Mollusc (*Echinospira*). × 12.
5. A medusa (*Neoturris pileata*). × 3.
6. Larva of Sea Urchin (*Echinus esculentus*), × 20.

It seems more probable that the stimulating influence lies in the presence of the moon, though quite how it acts is hard to imagine. More, as yet, we cannot say but we hope that in the future an explanation may be forthcoming. At any rate these lunar rhythms, probably of very common occurrence among marine animals, are receiving much attention from those interested in the science of the sea.

CHAPTER XII

Methods of Oceanographical Research

UNTIL the nineteenth century the great oceans of the world were comparatively little known to man. That is to say, although by then much of the actual geography of the seas had been mapped out, the world that lived beneath the surface of the water and the conditions to be found there were as a closed book to mankind.

At this day our knowledge is considerably increased and a study of the ways and means by which the discoveries have been made discloses the obvious dependence of oceanography upon the advance of other branches of science and the improvements of mechanical engineering. For exploring the greatest depths of the ocean, for instance, the advantages to be gained by the employment of steam or motor winches for hauling in the great weights of gear and rope are manifest. The introduction of wire cable to replace the hemp ropes in 1874 inaugurated a noteworthy advance. The ropes required for heavy work had, of necessity, to be extremely thick, and the space required to stow many thousands of fathoms of such material was great, whereas very much thinner wire provides the same strength and takes up infinitely less room, and can be kept wound upon the drum of the hauling winch.

One of the first investigations in a study of the sea was to find the depths at which the sea floor lay below the surface from place to place. While originally the purposes of sounding were to aid in navigation, and the depths in only comparatively shallow waters were sought, with the

introduction of submarine telegraphy a study of the contours of the bottom at all depths became necessary for the laying of the great transoceanic cables.

In shallow water the usual method is to heave overboard a lead weight attached to a length of rope which is marked off at intervals with pieces of leather and other materials to indicate the depth in fathoms. The lead weight is usually from ten to fourteen lbs. and has its bottom hollowed out to form a cup into which is put some tallow (Fig. 53). On striking the bottom the bits of sand or pebbles adhere to this grease and the navigator is thus enabled to discover the nature of the bottom over which he is passing.

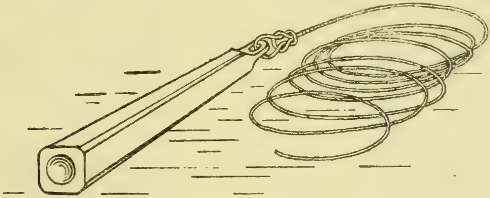
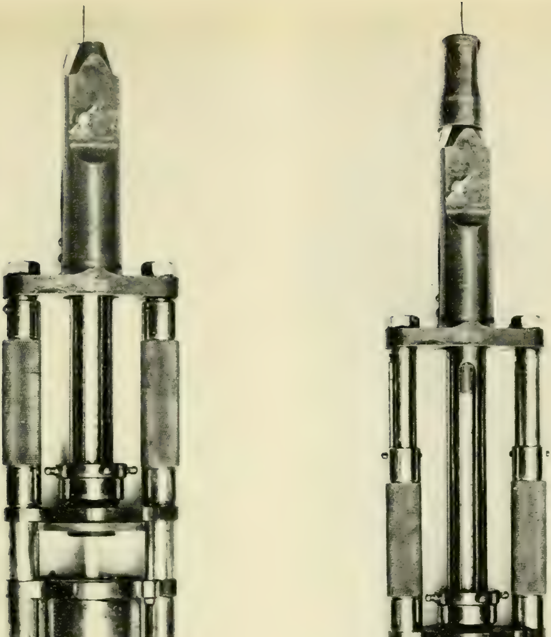


FIG. 53.—Sounding lead, showing hollow for "arming" with tallow.

For sounding in deep water a machine is always used and the sounding line itself is made of thin steel cable, which passes over a grooved wheel each revolution of which corresponds to a known length of wire. In very great depths it becomes impossible to feel when the lead has struck the bottom, because the weight of the many fathoms of wire in use is sufficient to continue unwinding the drum on which it is coiled But by the employment of a brake, however, which can be tightened up to counteract the increasing weight of the wire as it runs off the drum, the machine becomes so delicate that the moment the weight touches the bottom the brake acts and the depth can be

read off a dial. When a very large amount of wire is off the drum, its own weight comes dangerously near its breaking strain and there is a risk that, when it and the lead weight attached are hauled in, a break may occur. This difficulty is overcome by employing a specially designed weight which consists of a number of separate sinkers, and on the lead striking bottom these are released and the weight to be hauled up is thus considerably reduced.

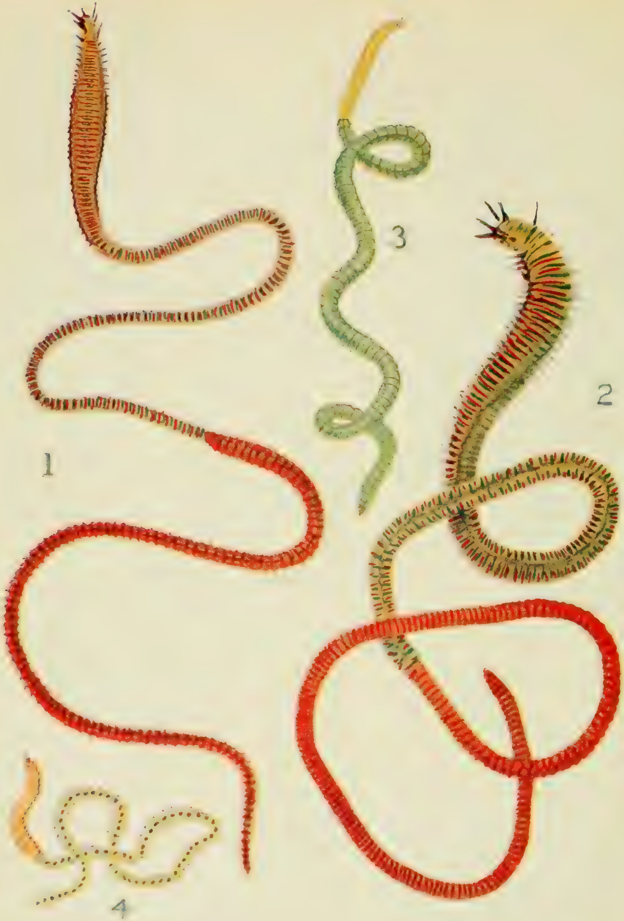
In very recent years a much improved method of sounding has come into practice. This method is an outstanding example of the application of knowledge gained by research in other branches of science, being a combination of the use of sound and electricity. It is known as " echo sounding " and the principle of it is that a sound is sent vertically downwards to the bottom and a very delicate instrument picks up the sound once more as it is reflected back from the bottom, in other words it receives the echo. Now the rate of travel of the waves of sound through water is known (about 4,900 feet per second) and by noting the interval of time between the first transmission of the sound and the reception of its echo it is possible to calculate the distance through which it has passed and hence the depth of the bottom. In shallow water this interval of time becomes extremely small, and it is only by the use of elaborate electrical apparatus that the time can be measured. With such an instrument a ship can travel swiftly through the water sounding almost continuously as she goes, and the time occupied in taking a reading is a striking contrast to that required with weight and line. The original word to " sound " (which is considered to be a form of the Old English word " sund," meaning " swimming ") would nowadays appear to have been very happily chosen and could not express better what is actually being done when a depth measurement is being taken.



Pl. 92. *R* 256.

Insulated water bottle. × ca. $\frac{1}{6}$. (p. 259).

Open. Closed.



Pl. 93. *R* 257.

Atlantic Palolo Worm *(Eunice fucata).* (p. 252).

1. Mature male, hinder portion ready to break off. Slightly reduced.
2. Immature male. Slightly enlarged.
3. Female sexual portion broken off. Slightly reduced.
4. Empty female sexual portion.

Of equal importance in navigation comes the necessity of knowing the speed and direction of the ocean currents. The bearing of currents on the distribution of the life drifting in the water layers is a problem that has received considerable attention in modern fishery research. Information can be gained about currents both directly by noting the movements of floating and drifting objects or actually measuring the speed and direction by special instruments, and indirectly by a study of the physical and chemical condition of the water itself from place to place.

In olden days much of the knowledge gained about ocean currents was acquired by the mariners themselves noting the position of drifting wreckage or derelict ships and as reports came in from different vessels it was possible to mark off on a chart the route taken by a drifting wreck and therefore to gain some idea of the general trend of the current. There was however a danger in basing too definite a conclusion on such observations, as the wreckage always had a portion above the water level exposed to the winds so that the path taken by such a wreck was therefore caused by a combination of wind and current. To-day information is sought by using specially constructed bottles which are thrown overboard at specified positions. They are known as " drift bottles " and they are used to study the water movements at the surface or near the sea bottom. The surface bottles are so weighted that they float almost completely submerged, and thus the least possible area is exposed to wind action. The bottom bottles are made just the slightest bit heavier than water and have fixed to them about eighteen inches of stiff wire; this wire trails along the bottom and holds the bottle clear of stones and other obstructions that might impede its movement as it is carried by the current (Plate 90). In each bottle is placed an addressed postcard with

directions printed on it in five different languages instructing the finder to place it in the nearest letter box after having filled in the place and date of recovery. Some of these bottles travel for enormous distances, and recently one which was liberated in the middle of the English Channel was picked up away on the coast of Norway having journeyed a distance of 1,440 miles in 190 days.

Currents can also be directly measured by means of special recording instruments. Several instruments have been invented, but there is one in general use to-day the principle of which is as follows. The machine is lowered to a given depth in the water and to it is fixed a vane which at once sets the instrument facing in the direction of the current. The current then acts on a small propeller which it rotates. Fixed to the instrument underneath is a small circular tray divided into a number of compartments corresponding to the divisions on a compass. After every so many revolutions of the propeller a little lead shot is released which falls on to the centre of a grooved magnetic needle, runs down it, falls off its North point into the compartment of the tray that lies immediately beneath it, according to the direction of the current. After a certain time the instrument is hauled up on board, and by counting the number of shot in the different compartments of the tray the number of revolutions of the propeller can at once be calculated, and from this the speed of the current; also at the same time, by noting the number of shot in each separate compartment, the direction in which the current has been flowing is at once given.

The indirect methods of attack depend upon the fact that the physical and chemical characters of the water vary from place to place. For instance the Gulf Stream water is notably saline, and by an examination of the

salinity its course can be roughly traced as it moves northwards. The physical state of the water and its chemical composition have an extremely important bearing on the life contained therein, and the temperature, density and saltness of the water are being kept continually under observation by those engaged in marine biological research in different regions.

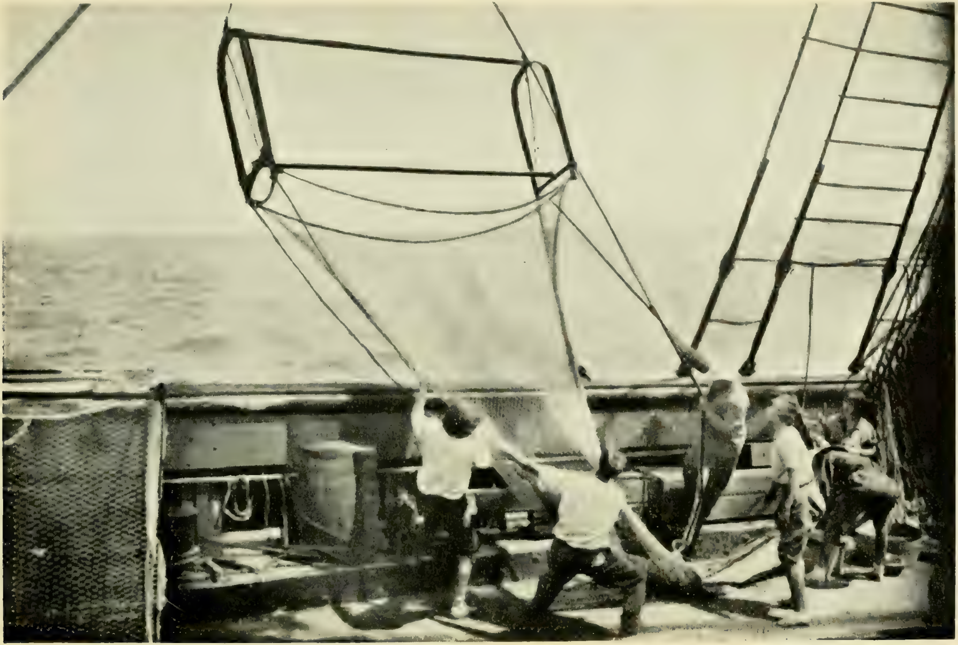
The chief instrument for studying the temperature of the sea is the thermometer. The study is a fairly simple matter when it is only necessary to find the temperature of the water at the sea surface. Water is merely dipped up in a wooden bucket and an accurate thermometer placed in it for two or three minutes ; it is important to use a wooden bucket rather than a metal one, because metal is such a good conductor of heat that in a short time it may materially affect the temperature of the water contained in the bucket and so lead to errors.

But it is quite another matter when we wish to know the temperature at fifty, 100 or even 1,000 fathoms. The water down to a certain depth becomes cooler as one goes deeper, and the first difficulty to be overcome therefore is that if a thermometer is lowered, say to fifty fathoms, it will pass through warmer and warmer water as it is hauled to the surface, and by the time it is examined it will be registering quite a different temperature from that actually occurring at fifty fathoms. This difficulty is overcome by using specially designed bottles that are thoroughly insulated. In addition, by means of a weight known as a " messenger " which can be sent down the wire, the bottle, which is lowered open at both ends, can be closed (Plate 92). On its downward journey the water merely flows through it, so that when it is closed it takes a sample of water from that depth at which closing took place. Owing to the insulation the water sample thus

obtained keeps its original temperature, and this is then read off from a thermometer fixed in the bottle itself. This is a reliable method when a knowledge of the temperature is required only in shallow waters but a further complication steps in if one wishes to study the deepest water layers.

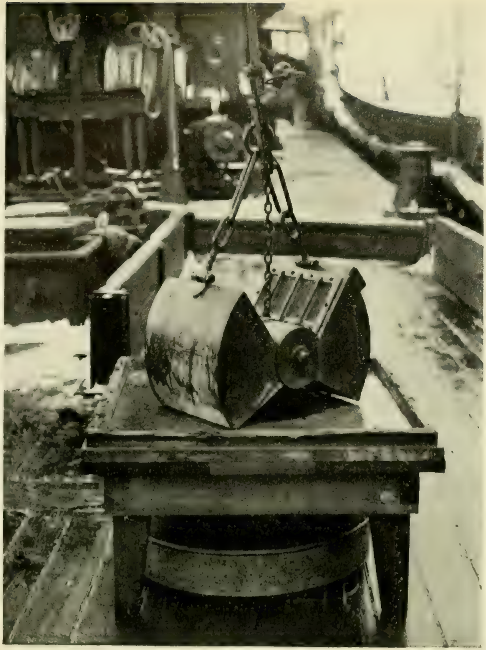
The water at this depth is under very great pressure, but when the sample has reached the surface the pressure is very much reduced. Now if water is compressed its temperature is slightly raised, and conversely if the pressure is reduced the water becomes cooled. In the passage of a sample in the insulated water bottle from a great depth to the surface, the water, cold as it was at the start, will be slightly colder when the observer reads the temperature. This error must therefore be counteracted. Accordingly a "reversing thermometer" is used, that is one in which there is an S-shaped bend, so that if it be suddenly turned upside down the thread of mercury is broken and a permanent record of the temperature is obtained. The thermometer on reaching the required depth is reversed by means of a weight which slides down the wire and releases a spring catch. Nowadays by using at the same time both the reversing thermometer and that enclosed in the insulated water bottle it has become possible to compile a table from which the error due to the release of pressure can be calculated, so that the water bottle can always be used. At big depths a thermometer enclosed in an outer case of thick glass is used as a safeguard against the pressure.

With the insulated water bottle samples of water are obtained, which, besides giving information on the temperature, can be drawn off into clean, stoppered bottles to await future chemical analysis. The water is subjected to extremely delicate examinations which give information



Pl. 94 S 260.

Agassiz Trawl. (p. 262).



Pl. 95.

S 261.

Grab, for taking samples of sea bottom, ×ca. 20. (p. 263).

Open.

Closed.

on the amount of salt contained, on the alkalinity or acidity, and on the presence of minute organic substances in solution.

A further physical observation that has to be made is the penetration of light into the sea. It is interesting to know the strength and colour of the light at different depths. A rough and ready way of noting the transparence of the water from place to place is to lower a circular, white disc to the depth at which it disappears. This method of course gives little information beyond a mere rough comparison of the transparency of different regions. Special cameras have been used which can be exposed for a definite time at any required depth, but they have yielded little information beyond recording the actual presence and colour of the light. Recently the light has been measured electrically by means of photo-electric cells and it is to be hoped that by this means an advance will soon be made in our knowledge of the light under the sea.

This completes a short outline of the methods used in studying the actual physical and chemical conditions in the sea—the depth, the currents, the temperature and so on. It yet remains to be said how knowledge is obtained of the living world present therein. All the various animals and plants that live either creeping on the bottom, or swimming or drifting in the water above the bottom, have to be captured and the methods of catching have to be well thought out because not only are the animals wanted in order that their structure may be examined, but also that numbers may be obtained showing their actual abundance from place to place and from season to season.

One of the first instruments to be used for the capture of animals from the sea bottom was the "naturalist's

dredge" (Fig. 54). This varies in dimensions according to the size of the ship from which it is to be used, but in essentials it consists of a rectangular or triangular shaped frame of iron to which is attached a short bag of strong netting. The mesh of the net depends on the size of the animals that are to be caught. The frame at the mouth of the net has sharp bevelled edges which can dig through the sand and gravel, and will scrape off any animals that are fixed tight to the rocks. This net is used for all sluggish bottom animals such as starfish, shellfish and sea urchins, and also for those animals that burrow in the surface layers of the sand or mud.

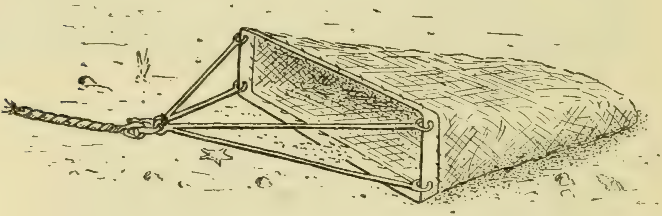


FIG. 54.—A naturalist's dredge.

For the swimming animals nets similar to those used by fishermen are employed. These, consisting of trawls, drift nets and seines, will be described in detail in the chapter on the sea-fisheries. In addition a small net known as the Agassiz trawl, named after its inventor, is used for deep-sea work (Plate 94). This net has the advantage that whichever way it may fall on the sea bottom it can still fish effectively, a very important point when fishing in great depths, as it is impossible to ensure that the net may not turn over several times in its long journey to the bottom.

Pl. 96.

Silk Tow-net, × ca. 20. (pp. 110, 264).

S 262.

Ring-Trawl Fishing at surface. (p. 265).

Pl. 97. S 263.

S.S. *Salpa* : Research Vessel of the Marine Biological Association.

A Steam Drifter (pp. 16, 268, 279).

By the means described above all sorts of animals may be captured for examination, but the instruments used cannot be said to be quantitative; they will not supply accurate information as to the abundance of the animals on the sea floor.

For this latter purpose an instrument known as the "grab" has been made. This is essentially the same as a coal-grab and is constructed so that when it strikes the bottom it literally bites out a piece of the sea bed. The instrument is very heavy, and consists of two hinged jaws which are open as it sinks to the bottom; on striking the gravel or mud the jaws sink in under their weight, and as the grab is hauled up they are pulled together so that a solid sample of the sea floor is retained (Plate 95). The sample is then sifted through a series of graded sieves and the sand and mud washed away. All the animals remaining in the sieve can be picked out and counted and so a knowledge of the population on a definite area of the sea floor is gained. Recently it has been shown that this grab or bottom-sampler is not completely efficient for studying life on hard sandy bottoms as owing to the firm consistency of the sand the grab does not sink deep enough and so fails to catch many of the creatures that live in their burrows a few inches below the surface. To meet this difficulty a new instrument has now been invented which possesses a pump which is put into action just when hauling-in commences. Until the pump has finished its work however the whole machine cannot be lifted off the bottom. The pump is operated by a wire running over a pulley wheel, and until all the wire is pulled off no strain comes on the instrument itself. With the suction set up by the pump the sampler sucks its way into the sand down to a depth of just over a foot, and so a sample of known area and depth is procured. On a similar principle is a little

sampler that collects a known volume of the detritus overlying the sea floor with all the microscopic life contained in it and in this case the method of effecting suction is very ingenious and no pump is required. The receptacle into which the sample is to be sucked is sealed with a glass disc. As this is done on the deck of the ship the pressure inside must be equal to that of one atmosphere. At the sea bottom the pressure inside the cylinder is still one atmosphere, but the pressure of the surrounding water is considerably greater. On striking bottom the glass disc is broken by a sliding tube with a point on it and, because of the difference in pressure inside and outside, a sample is forced into the receptacle.

It is a more difficult matter to find out how many fish there are in the sea. Fish can swim very fast and so avoid nets, therefore it is not safe to argue, from a catch of fish, that all those present over the area scoured by the net have been captured.

More indirect methods have to be employed and the chief of these is to mark the fish themselves, let them loose, and then find out how many are recaptured. More will be said about the marking of fish under the chapter on fishery research.

There remains the problem of catching the members of that huge drifting community, many of which are so extremely minute and delicate. The instrument *par excellence* of the plankton research worker is the tow net. This is simply a cone-shaped bag made of silk or other material attached to a ring (Plate 96). On the size of the meshes of the material naturally depends the size of the organisms which will be caught.

If only the larger animals are required, a coarse material will be used so that the smaller creatures will filter through and the catch will consist merely of the kinds of animals

that are wanted. The large drifting animals also are more widely distributed in the water so that a larger net will be required than for small plankton. In towing it is essential that as much of the water as possible will be filtered in the net's journey through the water. For this purpose the net itself is made very long, a length three times the diameter of the mouth being the general rule. For the larger animals the net generally used is the ring trawl which has an opening of two yards diameter and is about six yards long; there is thus a tremendous area available for filtering the water (Plate 96) The material in these big nets is hemp.

For the smaller animals the nets are usually about a foot and a half in diameter at the mouth and the material is silk. The coarseness of the silk depends on the size of the organisms required, the very finest being used for those minute drifting plants, the diatoms. The best silk is that used by millers for grading their flour through, known as bolting silk, and it has the advantage that the required size mesh can at once be obtained and that these meshes are so constructed that they keep a very constant size.

Much time has been spent in working out how much water the various nets will filter at different speeds of towing, because thereby it becomes possible to calculate how many creatures are present in a given volume of water.

In studying the distribution of plankton organisms in the different water layers it is necessary that the net should fish only at the required depth and not at all on its journey up and down. For this purpose nets have been constructed that can be sent down with their mouths shut; on arrival at the required depth the net can be opened, and when it has fished for long enough it can again be closed so that it catches nothing as it is being hauled up

to the surface (Fig. 55). In this way can be found the actual depth at which the different kinds of organisms live.

But besides the plankton organisms caught by the tow net, there are many forms so minute that they pass through the meshes of the finest silk obtainable. Their presence in the sea was first shown by an examination of the stomach contents of those small planktonic tunicates, the Oikopleura,

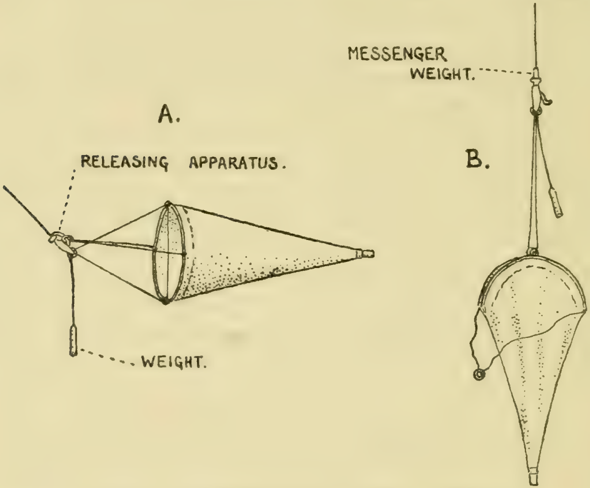


Fig. 55.—A closing tow net; A, fishing; B, closed.

whose houses and fishing apparatus were described on page 199. Many forms were discovered there which had never been seen before in any of the tow net catches, so that a new method had to be devised to obtain them in sufficient quantity to throw light on their distribution and importance. It was found that this could be done if a sample of water was centrifuged in a small pointed tube. Samples of water

are obtained by means of a pump and rubber hose let down to the desired depth, or, better, in the water bottle mentioned above for the collection of water for chemical examination. The water is then placed in small glass tubes, which taper to a blunt point at the bottom end, and centrifuged for two or three minutes. The surface water is then poured out of the tubes and the little drop that remains at the bottom contains the minute plankton organisms. This drop of water is sucked off with a glass pipette and spread evenly over a glass slide with squares ruled on it which can then be examined under a microscope and the organisms present in a given number of squares counted.

Much interesting work on the geographical distribution of plankton can also be done on ocean liners. If small silk filters be hung under the salt-water tap in the bathroom many of the surface-living animals and plants can be obtained.

One of the most important items in the equipment for oceanographical research is naturally a research ship. On big expeditions a vessel of large size is necessary if the object is to study the physical and biological conditions over extensive areas and at all depths. There must be plenty of space to stow the many and varied instruments and nets. A steam-driven winch capable of holding several thousand fathoms of strong wire cable has to be used for working the nets at great depths, and probably one or two smaller ones for working small plankton nets, sounding, and collecting water samples. Space should be available on board for a working laboratory in which the collections can be sorted and preserved, and accommodation should be provided for a small library of the most necessary works of reference for the identification of animals and plants.

The costs of equipping and running such a ship are heavy and beyond the means of the private individual. A few fully equipped research vessels are regularly employed by the governments of various countries for routine research in the area of the great sea fisheries (Plate 97) ; occasional expeditions are also sent out to study conditions in the open ocean, financed either by governments or private subscription.

But this is not to say that research cannot be carried out at sea without a large steam vessel. Much information of the most fundamental importance has been gained by working from small sailing or motor driven craft. Many of the basic principles underlying marine biological phenomena have only been discovered by exact and minute study within only a small area of the sea, and to this end a small boat equipped only with the necessary apparatus for some special branch of research is all-sufficient.

There remains the marine laboratory, accounts of some of which have been given in the first chapter. Their importance in oceanographical research cannot be overestimated. Much has yet to be done in the way of description of the life-histories of many animals, and the different stages of development have to be carefully drawn in order that they may be recognized when taken in collections by future workers. Under laboratory conditions even the most delicate animals can be reared from the egg and their identification thus becomes certain. Other fundamental problems can be tackled in the laboratory and mention may be made here of one concrete example.

It has been the aim of marine research workers to get as near a true evaluation of the sea as possible. By counting the planktonic organisms in a given volume of water after centrifuging it was found that there were fourteen organisms in a cubic centimetre of water taken

from the sea near Plymouth. It was thought that this represented a true picture of the density of population until an ingenious laboratory method for counting the organisms present was devised. In the laboratory half a cubic centimetre of water taken from the sea was added to a large volume of sterilized sea water. This large volume was then divided into seventy parts, each of which was put into a separate flask. These seventy flasks were then allowed to stand for several days, and on examination it was found that "cultures" of various organisms had grown in them. On the assumption that each culture of each species must have sprung from at least one individual of its kind, which must have been present in the original half cubic centimetre, it was found that the original number of organisms present in the sea water was at least 464 per cubic centimetre—a considerable advance on the fourteen found by the centrifuge method, which was evidently not fully efficient.

CHAPTER XIII

The Sea Fisheries

THE British Isles are situated in the midst of seas unrivalled for their productivity of fish life. Around their coasts lie the greatest sea fisheries of the world. In 1924 the value of the sea fisheries to Great Britain and Ireland reached the immense sum of twenty-one million pounds—three times as great as that yielded by the fisheries of any other northern European nation, France coming next with a total of seven million. In fact the value of our fisheries amounted to nearly half of the total value of those of all the northern European countries put together. But seeing that practically the whole of this fishing area lies outside territorial limits these great sea fisheries should be regarded as international in character, and as such their total value exceeds that of any other region of the world. Compared with Great Britain and Ireland the next great sea-fishing nation is Japan, the land of another island race. Whereas in our country only some 80,000 men are employed, in Japan something like two million men are engaged in catching fish, but this inequality is due to the fact that while in our seas the greatest catches come from powerful steam trawlers with their small crews, the Japanese are dependent for their supply on the efforts of large numbers of men fishing from small boats around their coasts.

The sea fisheries may be divided roughly into deep-sea and inshore fisheries, and of these the deep-sea are by far the more valuable. Amongst the inshore fisheries are

Pl. 98. S 270.

Hauling a drift net with catch of herring. (pp. 278, 279).

Trawl alongside. (p. 273).

Notice gallows and otter-board in background, glass balls for floating head line, and cod-end floating with mass of fish.

Catch on Board. (p. 273).

The fish have just dropped out of the cod-end.

classed the fishing for crabs, shrimps, lobsters, and mussels and oysters. This, the shellfish industry, is of great economic importance and is dealt with separately in Chapter XIV.

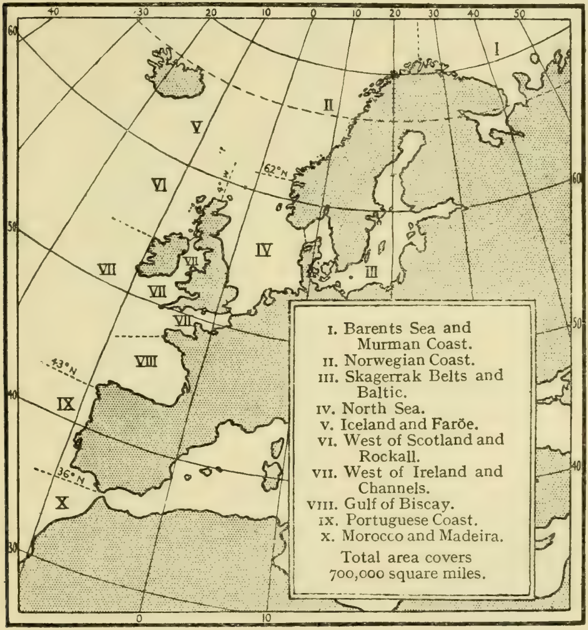


FIG. 56.—Map of the trawling grounds fished by British trawlers. The Roman numerals are the statistical regions.

The deep-sea fisheries other than that for the herring (Fig. 56) are on the whole carried out far from the land by steam vessels which may remain away from their port

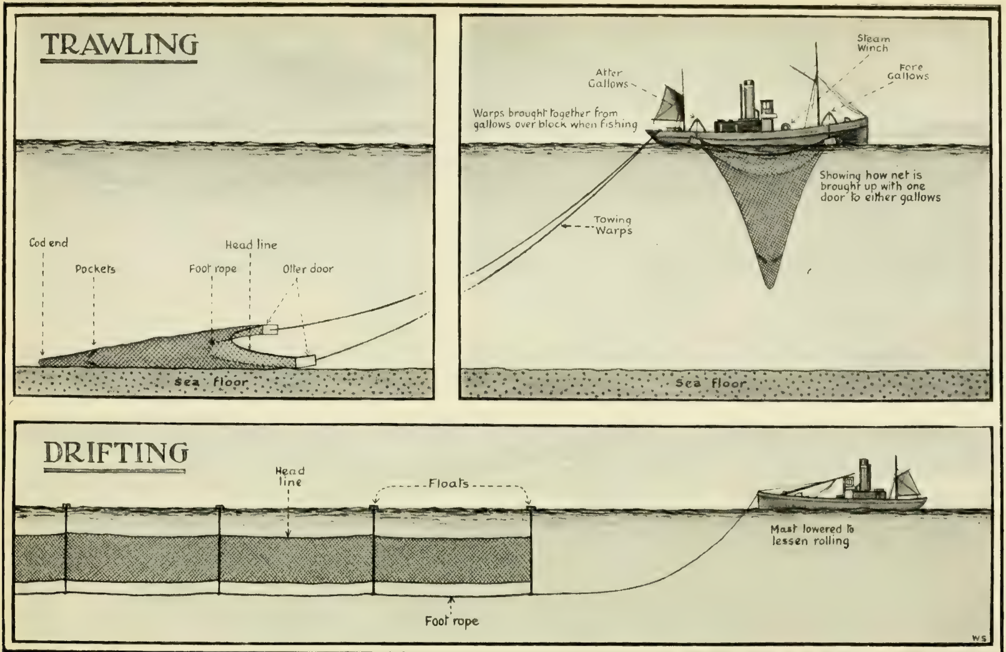
for two or three weeks. In olden days the fishermen, having to rely on sail alone, could not venture too far from their harbours, because of the time required to return to port and the consequent difficulty of keeping their catches fresh. But with the advent of steam vessels carrying large supplies of ice the fishermen have gone further and further afield, until now they range from Iceland and the White Sea in the north, to the Moroccan coast in the south. In consequence the steam ship has largely superseded the sailing vessel. But the picturesque brown-sailed trawlers and smacks are still to be seen sailing from Brixham, Plymouth and Lowestoft.

The type of ship used in these deep-sea fisheries is dependent upon the kind of fish that it is required to catch, whether it be fish living upon the sea bottom, demersal fish, or those that roam the water layers above the bottom, pelagic fish. For the former, the bottom fish, the vessel in general use is known as the trawler ; for the latter, the drifter ; each type being specially designed and equipped for the kind of gear it uses to ensnare the fish.

Trawling

The steam trawlers are the larger of the two, and they vary slightly in size according to the grounds they frequent, the vessels required for long voyages to such rough and inhospitable waters as the Iceland seas being the larger and more powerful. In general they range between 120 and 160 feet in length, but recently a giant of her kind, one over 200 feet long, was launched at Aberdeen for a French firm to fish Newfoundland waters. Besides being capable of carrying 500 or 600 tons of fish, she was equipped for extracting cod-liver oil.

The following are the main requirements of a steam trawler : low freeboard to help in the hauling of the net



Pl. 100.

Showing methods of Trawling and Drifting. (pp. 275, 279).

S 272.

Pl. 101. *S* 273.

Mullet net, Alexandria, Egypt. (p. 287).

over the side; a flush deck; a powerful winch capable of carrying many hundred fathoms of heavy wire rope for hauling the huge nets; a well protected propeller, and a capacious hold for storing ice and fish. The vessels are built of iron and are capable of speeds up to ten knots. The most up-to-date trawlers are fitted with electric light, and wireless, and a few even with refrigerating apparatus.

The net used is known as a "trawl," of which there are two kinds, the "beam-trawl" and the "otter-trawl," the former now being only used by sailing vessels. The net is of a flattened conical shape. The top edge of its mouth is straight in the case of the beam-trawl; while its lower edge is in the form of a hollow curve and has running along it a heavy "foot-rope"; this sweeps the ground as the net is fishing and stirs up the fish which, rising upwards, are swept into the mouth of the net. The net itself tapers away behind, narrowing down until the last ten feet of the net are reached; in this portion, known as the "cod-end," or "purse," the sides are parallel, and laced through the extremity is a rope, the cod-line, by means of which the purse may be closed by drawing tight (Plate 99). It is in this portion of the net that the fish collect, and on the arrival of the net on board, the contents can be emptied out by merely untying the cod-line. The fish, once having reached the cod-end, are prevented from swimming forward in the net again, and possibly escaping out at its mouth, by valve devices known as "flappers" and "pockets." The lower surface of the cod-end, that portion of the net which receives greatest wear by dragging over the sea bottom, is protected by stout pieces of old netting known as the "rubber" or "false belly," the under surface of the whole net itself being called the "belly." In these main essentials the nets used for either beam- or otter-trawls are much the same,

but a difference lies in the means by which the mouth of the net is kept open as it sweeps over the bottom.

In the front of the net in the beam-trawl is a frame, consisting of two D-shaped iron runners, known as " shoes " or " trawl heads," joined together above by a long and very stout wooden beam. To this beam the upper edge of the mouth of the net is attached, the short side of the mouth being fixed to the runners while the heavy foot-rope, curving backwards at the centre (Fig. 57), drags along the ground. The opening of the net is therefore determined by the size of this frame, its width being the length of the beam and its height the same as that of the shoes. The length of the beam may vary from forty-five to fifty feet

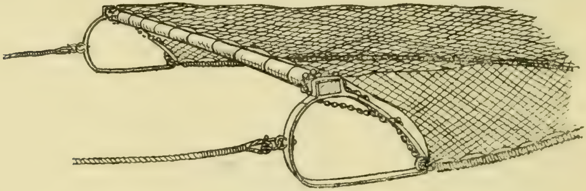


FIG. 57.—Beam-trawl, showing frame and front portion of net.

down to much smaller dimensions to suit the size of the boat in which it is used. The height of the shoes for a full sized trawl is three to three and a half feet, so that the largest opening a net could have would be a rectangle fifty feet by three and a half feet. The net itself may extend backwards up to 100 feet in length.

The principle upon which the mouth of the net is kept open in the otter-trawl is entirely different. In this case there is no frame to which the front of the net can be attached. Advantage is here taken of the fact that if a kite or any flat object set at an oblique angle be drawn

through air or water it will move in a direction outwards. The well-known method of poaching for trout by means of an "otter" is based on this principle. A flat piece of wood set at an angle is drawn through the water by the poacher on the bank. As he goes forward the "otter" also goes forward, but owing to the angle at which it is set it moves ever further out from the bank, towing behind it a string of lures which are thus presented to fish lying far beyond the reach of anyone upon the bank fishing in a sportsmanlike manner.

In the case of the otter-trawl two "otters" or "doors" are used. To these the sides of the net's mouth are attached, and they are set at such angles that as they are drawn over the sea bottom they diverge farther and farther from the centre of the net's mouth until an equilibrium point is reached and the mouth of the net is stretched agape (Plate 100) The upper edge of the mouth of the net is in this case not straight, but like the foot-rope it curves backwards, but the foot-rope is the longer of the two so that the net immediately behind the head-line forms a roof over it. The tremendous strain upon the bag of the net as it moves through the water keeps the mouth of the net open vertically. The otter "doors" are made of heavy iron-bound wood and are eight to nine feet in length, and four to five feet high. The lower edge that runs along the sea bottom is heavily encased with iron to form a shoe three inches thick.

In the case of the beam-trawl we saw that the opening of the net was limited by the size of the frame. Above a certain size the frame becomes too large and cumbersome for practice. With the otter-trawl, on the other hand, the opening that a net may have is limited only by the actual opening of the net itself, the "doors" being practically the same size for any net, their weight alone

being increased slightly for the larger nets. It stands to reason therefore that an otter-trawl can be used with a far larger opening than any beam-trawl, and for this reason it has largely superseded the beam-trawl. The height of the mouth also is not limited by a frame, and in an efficient otter-trawl it is probable that the upper edge of the mouth or " head-line " may be ten to fifteen feet above the bottom, so that the chances of a fish escaping over the top of the trawls are considerably decreased. These trawls are used nowadays with an opening of anything up to 100 feet in width.

This bag-shaped net is drawn over the sea bottom by the trawling vessel. The weight of these nets out of water is great and, when this large area of netting is exposed to the friction of the water as it is towed along, the pull is enormous. For hauling these great nets powerful steam winches are required, carrying on their drums wire cable sufficient to withstand a strain of many tons, for when by accident a net comes fast against a rock or submerged wreck the whole weight of the ship is taken by the wire.

Some skill is required for " shooting " these nets and an inexperienced hand might soon be in difficulties through the net and warp winding round the propeller of the ship, or going down belly upwards.

The net is hauled by two wire warps, one attached to each " door." These wires run over stout pulley wheels fixed in two heavy frames known as the " gallows," one forward and one aft. By the presence or absence of the " gallows " one can tell at a glance whether a vessel is fitted for trawling. On most trawlers there are two pairs of gallows so that the trawl may be " shot " from either side of the ship. Generally two nets are in use, and as soon as one has been hauled up full of fish on the port side, the starboard net is shot and so there is no waste of time while the catch is being emptied. While the starboard

net is fishing the catch of the port net is sorted and the net is prepared ready to shoot the moment the other net comes on board. While in most other trawls the "doors" are attached directly to the wings of the net, in a later type there is inserted between each door and the net itself a pair of warps the lower of which sweeps along the ground tending to drive fish inwards. In this way a wider area of the sea bottom is swept, and by using glass floats on the headline of the net its vertical opening is increased.

The great trawling grounds extend from the White Sea in the north, along the coasts of Norway, around Iceland and the Faröe Islands, the north of Scotland, the whole of the North Sea, and the Baltic, in all the waters that bathe the western shores of the British Isles, in the English Channel, the Bay of Biscay, southward along the coast of Portugal to the coast of Morocco (Fig. 56). Over all this area the catches vary much in composition, owing to the geographical distribution of the fish. The most important food fish caught in the trawl are the haddock, the cod, the plaice, the whiting, the hake, the coalfish and the dog-fish. Other kinds taken in smaller quantities are all flat-fish such as the sole, the turbot, and the brill; the skates, gurnards and many others. The catches of trawlers are divided into white-fish or round-fish such as the cod, and flat-fish.

Trawling is chiefly carried out in water down to 100 fathoms in depth, but some of the big trawlers when out for hake on the continental slope of the Atlantic have fished in water as deep as 500 fathoms, although 200 to 300 is the more usual depth. When fishing over rough ground, round rollers or "bobbins" may be attached to the foot-rope to prevent it catching in the rocks.

Although, as described below, herring are usually caught near the surface there are certain times when they frequent the bottom and an industry has recently sprung up for

catching these in the trawl also. When fishing for herring however the mesh of the net is somewhat reduced and the trawl is towed at nearly the full speed of the vessel, as opposed to the two and a half to four knots under usual trawling conditions.

Drift Fishing

Most of our food fish live on or near the bottom and can be scooped up by the trawl, but two or three species, such as the herring and the mackerel, live a great part of their lives swimming in huge shoals in the water layers above the bottom. In the daytime they are usually swimming rather deep in the water, but at dusk and during the night they come up very close to the surface itself. It is then that they can be most easily caught in the specially designed nets known as " drift nets." This habit of coming towards the surface at night is not peculiar to herring and mackerel. Those drifting animals that form the plankton show these habits and such vertical migrations are also common to many other fish. The hake is an excellent example ; so regularly does this fish leave the bottom at night that the fishermen never trawl for them except in the daytime, when they are on the bottom.

The drift nets by which the herrings are caught act on a principle very different from that of the trawl. There is no bag into which the fish are swept. A drift net is literally a wall of netting hanging vertically in the water, and in this case it is the mesh of the net that catches the fish (Plate 98). This mesh is made so that the herring can exactly push his head through, but not his body. When once the head has been pushed in beyond the gill-covers it is impossible to get it out again, because, the gill-covers being slightly raised, the twine of which the mesh is made slips under them. The herrings, swimming in vast shoals,

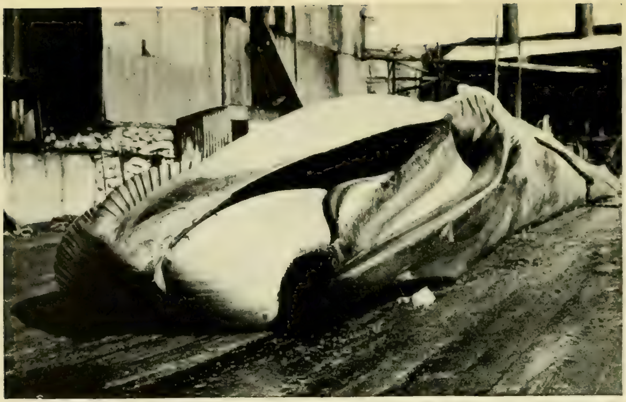
By kind permission of Harry Vanderwell, Esq.

T 278.

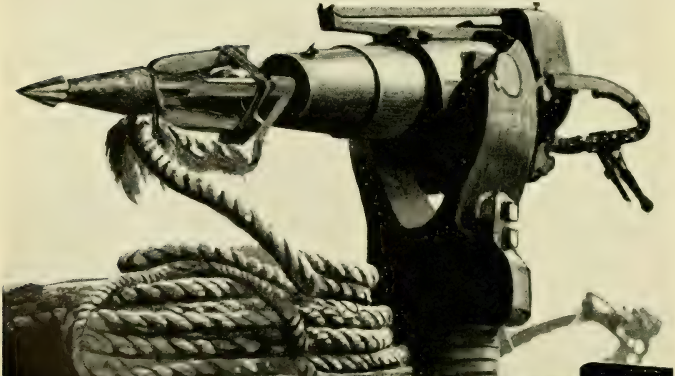
Pl. 102.

"On the great banks." (p. 284).

(From an oil painting by Norman Wilkinson.)



Whalebone Whale. (p. 289).



Pl. 103. *T* 279.

Whale Harpoon and Gun. (p. 290).

presumably cannot see this wall of netting in the dark and rush straight into it. Great quantities thus become enmeshed and strangled.

The vessel employed in this kind of fishing is known as a "drifter," and as with the trawlers many of these are now steam driven (Plate 97). The drifter is smaller than the trawler, being about ninety feet long, and having a speed of about nine and a half knots. The ships are not usually fitted with large trawling winches, but carry steam capstans on the forward deck, and the foremast is constructed so that it may be lowered when the vessel is fishing. The nets are generally thirty-four yards long and thirteen yards deep, and they are strung together so that they may form a wall of netting as much as three miles in length. The upper edge of the net is buoyed with corks, while the lower edge is generally slightly weighted with lead. Very often the net is not fished actually at the surface but a few fathoms down; it is then attached at intervals by short ropes to buoys or floats on the surface. When great lengths of net are used, as by the steam drifters, a strong foot-rope is attached at intervals by short lengths to the bottom of the net. When this rope is hauled on, it takes much of the strain of the heavy nets which would otherwise tear under the weight of a large catch. On smaller boats, however, the foot-rope may be dispensed with.

At about two hours before dark the fishermen start to shoot their nets, and this they do across the tide.

When the complete length of netting is out, the ship lies with one end attached to it and drifts for several hours with the tide (Plate 100). At about dawn, or even sooner, the nets are hauled over the side by steam power over special rollers, and the herring shaken out of the meshes as the many yards of net are piled down into the hold (Plate 98).

The herring fisheries lie all round the coasts of the British Isles, and the chief time for catching the fish is when they are approaching the coasts in dense shoals to spawn. Time of spawning is probably to a large extent determined by the temperature of the surrounding water and there are great differences in the dates of the spawning periods from place to place. The great drift fishery starts on the west coast of Scotland at Stornoway in the Hebrides in May; in June the herring are being caught off the Orkneys and Shetlands after which they begin to appear successively at different localities down the Scottish coast, until by the middle of July the fishery opens at Shields.

By the end of July, Scarborough and Grimsby are the chief centres of the herring industry, and early in October the fishermen are hard at work at Yarmouth and Lowestoft, the two leading herring ports. The boats from many ports follow this herring fishery round the coast, many Lowestoft boats for instance ending the herring season fishing from Plymouth, where the herring are spawning throughout the winter until January. There is also a herring fishery of appreciable value situated in western waters between the English and Irish Coasts.

The apparent advance of the herring southward along our east coasts gave rise to the idea that it was actually a migration of the herring themselves; that in the spring they collected in great armies in the Arctic Ocean and from there worked their way down our coasts. Thus, Mr. Pennant in his "British Zoology" in 1812 remarks, "The great winter rendezvous of the herring is within the Arctic circle: there they continue many months in order to recruit themselves after the fatigue of spawning, the seas within that space swarming with insect food in a far greater degree than in our warmer latitudes.

"This mighty army begins to put itself in motion in the

spring: we distinguish this vast body by that name, for the word herring is derived from the German, *Herr*, 'an army,' to express their numbers.

"They begin to appear off the Shetland isles in April and May: these are only the forerunners of the grand shoal which comes in June, and their appearance is marked by certain signs, by the number of birds, such as Gannets and others, which follow to prey on them: but when the main body approaches, its breadth and depth is such as to alter the very appearance of the ocean. It is divided into distinct columns of five or six miles in length and three or four in breadth, and they drive the water before them with a kind of rippling: sometimes they sink for the space of ten or fifteen minutes; then rise again to the surface, and in bright weather reflect a variety of splendid colours, like a field of the most precious gems, in which, or rather in a much more valuable light, should this stupendous gift of Providence be considered by the inhabitants of the British Isles."

But it is now generally agreed that this is a mistaken idea and that the herring may stay about in the deep off-shore waters not far removed from the region within which they spawn. It seems probable that while many may keep thus within comparatively short distance of the coasts, others may make considerable journeys even out into open ocean waters. It is thought that in adjacent ocean waters they grow faster than near the coasts, and it is possible to trace their movements each year by the rate of growth shown on their scales.

No fish in the sea are caught in such great numbers as the herring. One boat may catch over 100,000 fish a day and the total catch on such a day for Yarmouth would be 30,000,000.

This great fishery gives employment to an army of

workers on land, chief among which are the Scottish fisher girls. While the fishermen are moving round from port to port following the appearance of the spawning herring in each locality from north to south in turn, the fisher girls are following the fleet on land.

In October, Yarmouth, whose streets were thronged a month before with holiday makers, becomes crowded anew with these Scottish girls. Here they work all day cleaning and gutting the herring harvest with razor-sharp knives wielded in their dexterous hands. Like a flash the cut is made and the fish ready for preserving, and so they carry on all day, while others are employed in salting, packing, tending the nets and other multifarious tasks.

The value of herring landed in England alone in the year 1924 was about four and a half million pounds. The total value of the herring fisheries of all the nations of Northern and Western Europe was nearly ten million pounds, or a little under a quarter of the value of the whole sea fisheries. Expressed in weight this means that out of the two and a half million tons of fish landed by these European countries over one million tons consists of herrings, which is roughly equivalent to seven thousand five hundred million fish !

Seining

In quite recent years a new development has taken place in the British fisheries in net fishing in off-shore waters. This is the use of the Danish Plaice Seine. This is a bag-shaped net thirty feet in length, each side of which stretches out in front to form a " wing " eighty to 100 feet long. The " foot-rope " is weighted with lead and the upper rope is buoyed with cork or glass floats to keep the mouth of the net open. Attached to the front end of each " wing " are many fathoms of warp. When fishing one end of the warp of one wing is attached to an anchored

buoy. The vessel, which is motor driven or a small steamer, now goes down tide paying out this warp until it is all out. The net is now put overboard and the ship sails round in a semicircle paying out the other warp until it has returned to the anchored buoy. The two ropes are then taken on board and the net is hauled in by a special winch.

It is found that with this net the fish caught are in much better condition than those caught by trawls. In fact the plaice are generally in quite a lively condition and are kept alive on-board in tanks by Danish fishermen, amongst whom the net has been in use for many years.

This seine is also used for catching haddock, but in this case the wings of the net are generally shorter than those of the plaice seines.

The pilchard seine was a net used off the Cornish coast for catching pilchard in the days when this fishery flourished. When a shoal was sighted by special watchers or "hewers" from prominent points on the coast the fishermen rowed round it paying out the net as they went. This is very similar to a drift net, and when the circle is completed the pilchard are enclosed within a wall of netting. This circle of netting is then towed slowly towards the shore until the weighted foot-rope is on the ground. The fish are thus cooped up without any way of escape and the fishermen can remove them at their leisure by means of a smaller seine known as a tuck net. This net is very deep and when the fish are surrounded the bottom edge of the net is drawn towards the surface so as to form a bottom and the pilchard are then scooped out in baskets. When a very large shoal has been encircled in the pilchard seine the process of removing them in the tuck net has been known to take several days. A tuck net is also used in inshore waters for catching sprat.

The purse seine is a net used extensively in America for

catching the menhaden, which is a close ally of the herring, and the mackerel. A shoal of fish is surrounded in the same way as with the pilchard seine, but the net is made so that a rope can pull the bottom edge of the net together like the mouth of a purse so that the fish are completely enclosed in a basket of netting.

Lining

Fishing with hook and line is a method used extensively in some parts for cod. The cod-fisheries of the Newfoundland Banks are world famous and no more vivid description of the arduous life of the fishermen in those waters can be found than in Mr. Rudyard Kipling's *Captains Courageous*.

But the actual method of fishing by hand line, given in that book, has been largely superseded now by the use of long lines carrying anything up to 3,000 hooks each.

The vessels employed are mostly sturdy sailing craft, and each carries eight small rowing boats known as dories. When the banks are reached the dories are put out to lay their lines. The lines are baited with squid, herring, or capelin, and are each fifty fathoms long with about ninety hooks. Nine of these lines are coiled in a tub, and each dory carries four of the tubs. When fishing, all the lines are often joined end to end, making up one long line 3,600 yards long. In this way the eight dories of one fishing schooner may lay as much as sixteen miles of line. The hooks are attached at intervals along the line to short snoods about two feet long. These lines may be set in the morning, when they are hauled up three hours afterwards, or in the afternoon when they are allowed to remain down all night.

The fishing is carried out along the Newfoundland coast and on the Newfoundland "Banks" (Plate 102), in depths between fifteen and 130 fathoms.

Although the general practice is now to use these long lines there is still a certain amount of hand lining done. The hand line is quite short and has only two hooks on it. They may be used from the dories, or at times from the schooner itself when she is drifting. Each fisherman keeps count of the cod he has caught by cutting out their tongues, and throwing them into a basket to be counted up when fishing stops.

When the fish are all aboard they are cut open and cleaned, and packed away in salt.

Long lines very similar to those used in the Newfoundland fisheries are also used round the British Isles for cod, haddock, whiting and other fish.

Inshore Fisheries

Although somewhat hard to define accurately, the inshore fisheries may be said to comprise all those fishermen who make their livelihood around the coasts in motor or sail-driven craft, or from the shores themselves. The fishermen are rarely at sea for more than one night at a time.

Most of the fishing methods used by the steam trawlers and drifters can be used by these longshore fishermen, but the gear is of necessity lighter and smaller. Small plaice and whiting are caught in beam-trawls, and drift nets are used for herring. It is quite a common practice on the east coast for the fishermen to shoot their drift nets quite close inshore at sunset and leave them to drift along the coast with the tide all night, returning to pick them up in the morning.

Seines are used for pilchard, sprat and mackerel from sandy beaches. The rope attached to one end of the seine is retained on shore, and the men row out to sea allowing the net to run off the stern of the boat as they go.

After a certain distance they turn and, making a semicircular sweep, return to the shore with the other rope (Fig. 58). The seine is then hauled in, the two ropes being gradually brought closer together until the two ends of the net are on shore. The central and deeper part of these seines is generally bag-shaped and the fishermen drive

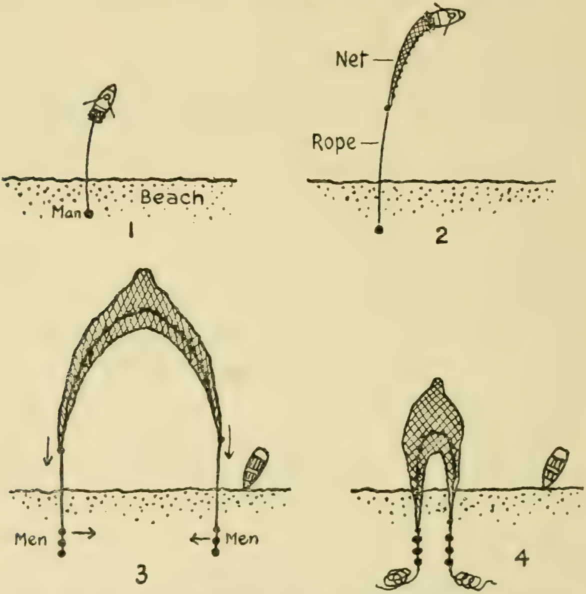
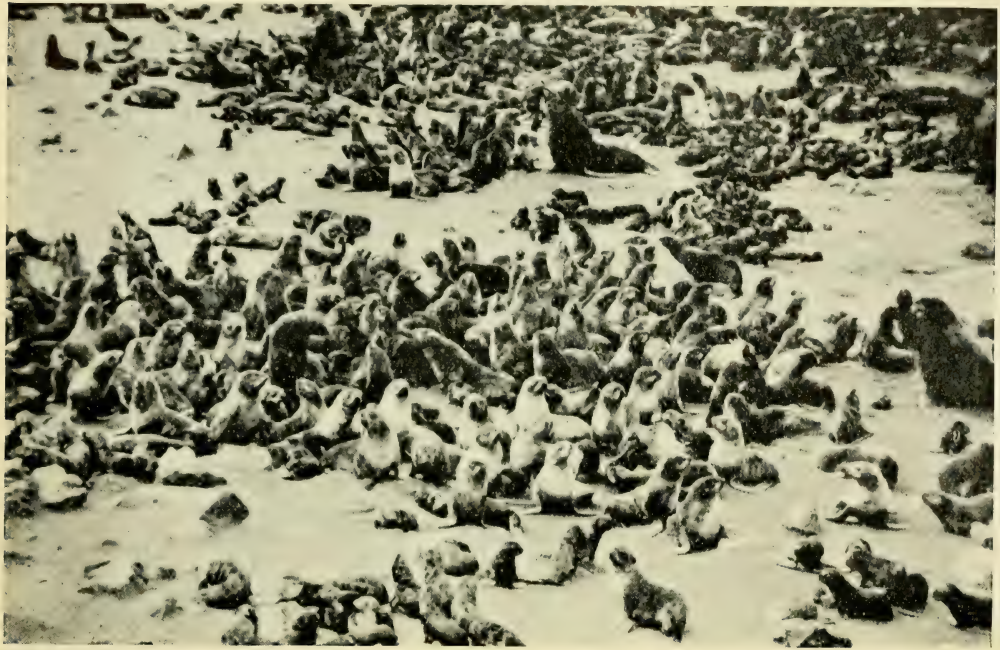


FIG. 58.—Diagram to illustrate the principle of fishing with a seine net from the shore.

the fish towards the bag by splashing as the net is being pulled up on to the sand.

The ebb and flow of the tides over flat sandy beaches is taken advantage of by the use of stake nets. Netting is



Pl. 104. *T* 286.

Fur Seal Harem. (p. 292).

Pl. 105 T 287.

1. Spat of Native Oyster on Scallop shell, $\times\frac{2}{3}$.
2 & 3. Spat and Adult Native Oysters (*Ostrea edulis*), $\times\frac{2}{3}$.
4 & 5. Spat and Adult Portuguese Oysters (*Ostrea angulata*), $\times\frac{2}{3}$.

(p. 294).

attached to a number of stakes set upright in the sand to form a trap with a small opening towards the sea which the fish enter on the incoming tide. When the tide recedes the fish are left high and dry on the sand.

In many parts of the world the ancient cast net is still in use. The net is so weighted that a dexterous throw from the shoulder will make it open out and fall flat on the water—a circular disc of netting whose weighted circumference carries it quickly to the bottom with any fish over which it may have fallen. By pulling carefully on a rope the weighted edges can be drawn slowly together over the bottom so that the fish is completely ensnared in the net. Along the Egyptian coast fishermen may be seen using these cast nets for grey mullet which they stalk in the shallow water.

Very often in the devising of nets advantage is taken of some peculiarity in the habits of a fish, such as the drift nets which are used for catching the fast swimming shoals of herring or mackerel. The grey mullet is a great jumper and will leap out of the water when it meets an obstruction. If a shoal of grey mullet be surrounded by a seine great numbers may be seen making their escape by leaping over the walls of netting. In the eastern Mediterranean a net is used which besides presenting a vertical wall of netting, has netting lying horizontally on the surface supported on floating bamboos. This net is shot off the stern of a boat, which is rowed in a complete circle so that a shoal of fish may be completely surrounded by a hanging curtain of netting (Plate 101). The mullet immediately jump; but, instead of leaping over the wall as they intended, they find themselves flapping and splashing on the horizontal floating net on the outside. The fishermen row round and pick them up as they jump to their fate.

There is a net used by the Japanese which requires

twenty-five to thirty boats and 150 to 200 men to look after it. This is a huge bag net 900 feet long with a mouth 250 feet wide and 125 feet deep; the wings of this net which stretch out on either side in front of the mouth may be as much as 3,000 feet in length. It is used for catching the yellow-tail or amber-fish.

Hand-lining is a common practice among inshore fishermen, and long lines on the same style as those used in the cod fisheries are also employed. Lines may also be set in the sand at low-water mark which are covered by the rising tide and can be taken up when the water has again receded.

Many fish such as mackerel and pollack can be caught by trailing a shining spinner behind a boat, and one man can operate as many as four lines.

Whale Fisheries

Whale hunting has been popular for many centuries, but probably the first real whaling industry was founded by the Basques of southern France and northern Spain. This fishery was situated in the Bay of Biscay, and was started in the tenth century when the Atlantic Right Whale, or Biscay Whale, was the object of pursuit. From the tenth to the sixteenth centuries the fishery was centred round the towns of Bayonne, Biarritz, St. Jean de Luz, and San Sebastian and from here the rest of Europe was supplied with whalebone and oil.

The whole history of the whale fisheries has been one long story of extinction through man's want of thought for the future, and by the sixteenth century the Biscay Whale was becoming very scarce, and possibly shyer, and the Basques had to go farther afield in their chase, often voyaging as far as the coasts of Newfoundland.

About the sixteenth century the existence of the Greenland whale became known, and Europeans turned their

attention to the northern waters that it inhabited. This gave rise to the great Spitzbergen fishery which was exploited both by the British and the Dutch. These whales were very abundant, and apparently, at first, tame and easy to capture ; as a result the slaughter was wholesale, and by the end of the nineteenth century the Greenland whale was practically exterminated, so that these fisheries exist no longer.

At the present day the northern fisheries are practically confined to the capture of the Rorqual, or Fin Whale, by the Norwegians. This is a very fast swimming whale and it was not until the invention of the explosive harpoon in 1866 that any serious attempt at capturing it was possible. Owing to its great vitality the old method of capture by hand harpoon was practically useless and extremely dangerous for the fisherman. But while in the first years of the twentieth century these northern fisheries were the most important in the Atlantic Ocean, now the chief hunting grounds are in the frozen south. The whales chiefly taken in the Antarctic are the Blue whale, the Fin whale (Plate 103) and the Humpback, and the most productive waters centre around the Falkland Islands. Here, as in the North, the fishery is mainly carried out by Norwegians. At the present day signs are not wanting that even these fisheries may be on the decline, the Humpback whale, which in 1910 formed a very high percentage of the catches, now being largely superseded by the Blue whale. As a result the Falkland Islands Dependencies in 1924 financed an expedition to study the life-histories of the whales. During the last three years this expedition, in Captain Scott's old ship the *Discovery* together with a specially built whale catcher the *William Scoresby*, has carried out a scientific survey of the whaling grounds. Little is known of the migrations of whales and the ex-

periment was tried of marking the living whales with numbered metal discs. These discs were shot from harpoon guns and adhered to the body of the animal by stout points which penetrated the blubber. It is hoped that the recapture of these whales will throw light on their movements.

In the early days of whale fishing the chase must have been fraught with danger and excitement, for the hunters ventured forth in frail boats and came to close quarters with the whale in order to drive their harpoons in by hand. A whaling vessel usually carried six of these small chasers, sailing boats twenty-seven feet in length.

To-day the whale chaser is a steam driven steel ship of anything up to 130 feet in length and capable of speeds of thirteen to fifteen knots. The harpoon is shot from a gun and is itself six feet long and 100 pounds in weight. It has four barbs, each a foot long, which spring out when the harpoon is buried in the whale's flesh ; in the nose of the harpoon is a small shell loaded with powder which is exploded by time fuse and helps to hasten the end of the whale (Plate 103). Attached to the harpoon are 1,000 fathoms of stout rope on which with the help of a steam winch the whale is played.

The captured whale, with air pumped into it to make it float lightly, is towed back to harbour where the factory is situated and there the blubber is stripped off it and other parts are put through the various processes necessary for producing the oil. The whalebone is cut off and the meat is cut into chunks and packed in boxes ready for shipment.

In order to remove the blubber, incisions are made along the whole length of the body. A stout hook is then inserted into the blubber at the head end and by means of a chain and winch the blubber is stripped from the body,

while men stand by with sharp knives to part it cleanly from the meat.

When fishing in distant regions where it is not possible to establish a shore factory, large vessels are used capable of performing the final operations on board. The ships generally anchor in some sheltered bay and form a base for their attendant whale catchers to work from: the whales are here drawn up on to the shore to be cut up.

Recently an experiment has been tried of employing a ship specially fitted with a slip-way through which the whole whale may be hauled through the stern and stripped and cut up on board. Such a ship can do all the factory work at sea and follow its own whale catchers from place to place.

Seal Fisheries

Almost all species of seals are of commercial value for their hides and blubber, but the most important by far are the sea-bears or fur-seals whose warm furs maintain the sealskin industry.

Like the whale, seals have been wantonly massacred by the hand of man and in many parts of the world they have been hunted to the verge of extinction. At one time the great herds of the Antarctic exceeded those in any other region, but now they have been reduced to only a few numbers.

At the present day the chief sealing grounds are in the Behring Sea on the Pribylov and the Commander Islands. Although originally these seal herds which numbered several million individuals suffered considerable depletions, the Russians by whom they were exploited showed great forethought. Knowing that the seal was a polygamous creature they took great care to save the female population and killed off only the superfluous males. These seal

fisheries, which passed into the hands of the United States of America through the sale of Alaska by the Russians, are now controlled by the American Bureau of Fisheries. Killing is confined only to three year old males and a large number of this class are conserved for breeding purposes. When the seals are all assembled on the land for breeding each male gathers round him a harem, averaging about thirty wives (Plate 104). When all the harems are collected the remaining superfluous males or bachelors are kept away from the breeding grounds by the married males and so can be easily herded together and driven off to the killing grounds by the sealers. The killing grounds are situated some distance from the breeding area so as to prevent disturbance there. When the seals have been chosen for slaughter they are knocked unconscious by a blow on the head with a heavy club and rapidly bleed to death while in this condition.

Towards the end of the nineteenth century these seal herds ran great risk of extermination from the practice of pelagic sealing. Advantage was taken of the migratory habits of the seal and, when in the spring the herds were returning northwards along the Californian coast, to the Pribylov Islands, men went out in sailing ships to shoot them. In this way great harm was done, for not only was there wanton destruction of females, but the death of every female meant the death of at least one pup for future years. After protracted discussions this pelagic method of sealing was prohibited in 1911, and it is satisfactory to see that under the care of the American Government the latest census of the seal population shows a large increase.

CHAPTER XIV

The Shellfish Industry

SECOND only in importance to the true fish as a source of food from the sea come the shellfish. To a scientist shellfish signifies Molluscs, such as oysters, mussels, scallops, whelks and the like ; but as used in commerce the term also includes members of the crab and lobster family, or Crustaceans, and it is in this inclusive sense that it is here employed. Though in Great Britain, owing to the great size of the fisheries, the shellfish industry is of comparatively small importance, this is by no means the case in many other maritime countries, while in this country there is a great field for development especially in connection with the molluscan shellfish which, with the exception of the highly esteemed oyster and scallop, are unjustifiably despised by a large section of the population.

MOLLUSCS

Shellfish have been consumed by man from time immemorial as is shown by the presence of shell heaps, often of great dimensions, near the dwellings of prehistoric man, and so arranged that it is almost certain they are the work of man and not of nature, while animal bones and rude weapons have occasionally been found in them. On an island off the coast of California a primitive race of people who lived largely on shellfish are said to have survived until the nineteenth century. Oysters have long been regarded as a delicacy, to such an extent by the Romans

that, according to Pliny, they endeavoured with apparent success to increase the natural supply by cultivating them artificially in Lake Lucrin, and Roman funeral vases from the time of Augustus have been discovered on which are designs showing the method of cultivation.

There are many species of oyster but only two inhabit the coasts of Europe, the "native" oyster (*Ostrea edulis*) and the Portuguese oyster (*Ostrea angulata*); the former, as shown in Plate 105, being round and flat, and the latter more elongated and deeper, while, as we shall see, there are other important differences between them. The Portuguese oyster, as its name tells us, is a more southern species and was originally found mainly around the Iberian Peninsula; but of recent years it has spread northwards along the coast of France at the expense of the more highly esteemed, but much less hardy, native. The latter is still the only kind of oyster found around the shores of Great Britain, where the water is too cold for the Portuguese oyster, and it also occurs northward along the west coast of Europe as far as the middle of the Norwegian coast, though the most northerly fishery of any great importance is in Denmark. The oyster is largely a shallow-water animal with a preference for estuaries, and this has made possible its artificial cultivation, which forms an important industry in many parts of the world especially in France and Japan.

Oyster Cultivation

The history of oyster cultivation in Europe is a fascinating one. As we have already seen, in this, as in so much else, the Romans were the pioneers, and it is probable that the crude methods of cultivation in use at the present day on Lake Fusaro, and in the Gulf of Taranto in Italy, have been handed down from the days of the Romans.

Oyster Park at Arcachon.
Collection of oysters for market. (p. 298).

Pl. 106. *U* 294.

General view of oyster parks at low tide. (p. 298).

View of oyster park at Arcachon, tide rising, showing "collectors." (p. 299).

Pl. 107. U 295.

Tiles from "collectors" at Auray. (p. 299).

It was certainly an examination of these by the French Professor Costé which resulted eventually in the development of the great modern French oyster industry. The increasing popularity of oysters among the French in the early nineteenth century led to a more and more intensive fishing of the fine natural oyster beds with which the western coast of France is dotted, and though for many years this seemed to have no effect on the number of oysters collected yet finally the natural rate of increase was overtaken and stocks began to diminish, to such an extent that, to quote but one example, 70,000,000, oysters were dredged in the Bay of Cancale in 1843, and only about 1,000,000 from the same locality in 1868! All along the coasts of France the oyster beds were depleted in a like fashion, and the government had finally to step in, drastically restricting oyster dredging pending scientific investigations.

It was the boundless enthusiasm of Professor Costé of the Collége de France which eventually turned disaster into abiding success. The first experiments consisted merely of attempts to restock the old beds by means of imported oysters. Experiments of this nature carried out near St. Malo in Brittany met with great success, and it was realized, for the first time moreover, that young or "spat" oysters could be collected artificially on fascines or bundles of twigs just as successfully in France as they had been in Italy. To make this clear we must say a little about the life-history of the oyster. The adult oyster is the most sluggish of animals; fastened to stones or rocks at an early age it is incapable of locomotion and is only moved by currents powerful enough to move the stone to which it is attached. But the young oysters—produced annually in countless millions, for a single oyster may produce millions of eggs in a single season—are unattached

for the first few weeks of their existence and rise near the surface of the sea where they are carried in all directions by tides and currents (Fig. 59). At this stage they have a pair of tiny shell valves between which project a crown

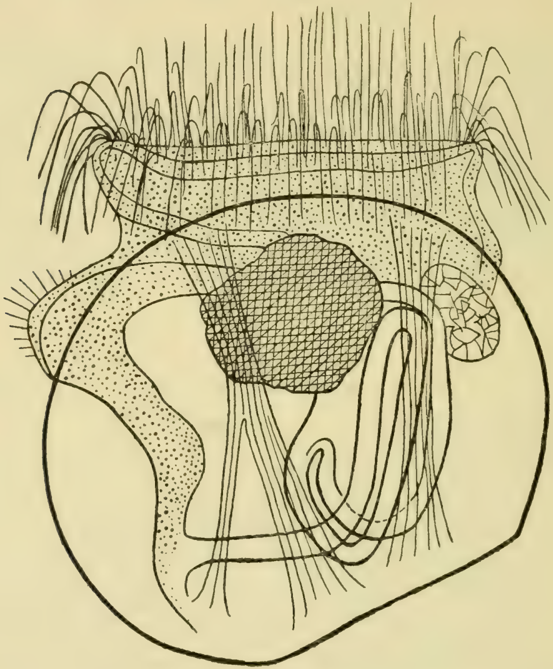


FIG. 59.—Larval stage of oyster, greatly enlarged.

of fine hairs by the rapid movement of which they swim and collect their food. At the end of their brief period of freedom the little oysters, or such of them as have

survived the attacks of their numerous enemies, sink to the bottom. Even there their troubles are not at an end, for they can only attach themselves to clean hard objects such as stones and shells ; if the bottom is of sand or mud or if the stones are slimy with weed the oysters must die. Should the right conditions be found, the oyster fixes itself with a kind of cement, left side undermost, on to the first hard surface with which it comes in contact. It now quickly changes its appearance and both shell and the contained body grow rapidly, so that soon, although less than one-eighth of an inch in diameter, it has all the organs of the adult oyster in miniature. It is now merely a question of time, abundance of food, and immunity from predatory foes such as starfish and crabs, before the oyster becomes fully grown.

The discovery that oyster spat would settle upon artificial collectors like brushwood immediately fired the imagination of Costé. He foresaw that, not only would it be possible to restock the depleted beds, but, by collecting spat wholesale, to cultivate oysters on an immense scale. The Emperor Napoleon III became interested in the schemes and two Imperial oyster parks were established in the shallow Bay of Arcachon, south of Bordeaux. The experiment was a brilliant success ; 2,000,000 oysters had been imported and from these, immense numbers of spat were obtained on a new type of collector consisting of planks covered with pitch or resin, the latter, with the attached spat, being subsequently broken away from the woodwork. Later years, however, were not so successful and many of the oyster cultivators lost heart and abandoned their attempts. A great step forward was made by an unknown seaman who suggested using half-round roofing tiles as collectors and these proved to be ideal for the purpose but expensive as they had to be broken up in order to

separate the spat. The next stage in development was reached when the tiles began to be coated with substances which could later be flaked off without damaging the tile and a number of attempts were made before the perfect method was found by an Arcachon mason named Michelet. This method, discovered in 1865 and now universally adopted, consists in coating the tiles with a mixture containing definite proportions of lime and sand.

Costé did not live to see the success of the industry he had founded, he died neglected and in poverty, but Michelet, the practical man, lived to turn Costé's dreams into the routine methods of a great industry. The spat collected on the collectors after it had grown to suitable size, was detached by flaking off the lime beneath it; the tiny oysters so obtained—far too small to be exposed on the beds—were placed in "ambulances" devised by Michelet. These are shallow boxes on short legs and covered over with wire netting above and below, in which the young oysters remain until they reach a size when they can safely be laid on the open beds.

To-day the Bay of Arcachon is the greatest centre of oyster rearing in the world, four to five hundred million oysters being exported every year. The Bay is almost land-locked with only a small opening to the sea, and, while at high tide the sea covers some 37,000 acres, at low tide great stretches of sand and mud are exposed, more than half the area of the Bay being uncovered at spring tides. Almost the whole of this exposed region between tide marks is covered with oyster parks such as those shown in Plate 106, each of which is surrounded on its outer side by a palisade of small twigs which serve to protect the oysters within from the attacks of marauding fish and which are the only indication of the presence of the parks when the tide is full. Within the parks the

surface, on which the oysters are laid, is kept clean and free from the ubiquitous crabs and starfish, the oyster cultivator's greatest enemies. In the early summer the collectors (Plate 107) are arranged in preparation for the spat which will appear as soon as the water becomes warm enough for the oysters to start breeding, and in preparation for this the tiles are scraped clean and relimed, and later arranged, concave side downward, as shown in Figure 60, in crate-like wooden cases. Great numbers of these collectors are put out just below low-water mark, where the tiny swimming oysters will be washed against them every time the tide retreats, and, if there is a good "fall of spat," the tiles soon become covered with hundreds of transparent specks, each of which represents a future marketable oyster.

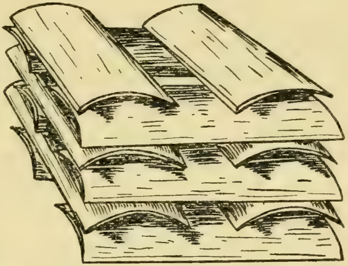


FIG. 60.—Oyster "collectors," showing manner in which tiles are arranged.

The collectors are allowed to remain in the water until the beginning of the following year, care being taken to keep them clean and free from encrusting plants and animals which might smother the spat. As soon as the weather is good, perhaps as early as January, but in some years not until May, the tiles are brought ashore, so many at a time, to a shed where "détroquage," as the process of separating young oysters from the collecting tiles is called, is carried out. Girls are largely employed in this work, each one stripping on an average some 200 tiles per day. For the time being the oysters are placed on wooden trays in a storage tank, but as soon as possible they are picked out, cleaned and separated into different sizes,

after which they are taken back into the parks and placed in "ambulances." These may hold at first as many as 15,000 young oysters, but as growth proceeds this number is steadily diminished by the transference of many of them to new ambulances or on to the open beds. The ambulances, being raised on legs some little distance from the ground, protect their contents from all danger of suffocation by mud which, under normal circumstances, is responsible for the destruction of countless numbers of newly settled spat. The cases are examined repeatedly and all enemies removed. Meanwhile the old tiles have been scraped free from the old coating of lime, washed, and stacked away in preparation for the new season, before which they will be relimed.

Oysters are not exported until they are about two years old, and about two inches in diameter. They are then, of course, not of marketable size but are sold to oyster fattening farms of which those in the neighbourhood of Marennes are the most famous. Many also are exported to Spain and some to England. Oysters which are sold for immediate consumption are usually from four to five years old, and these are produced annually in tremendous numbers, and sent all over France and to many other parts of Europe. The process of oyster rearing is carried on in many other places along the west coast of France, though nowhere are the conditions so ideal nor the industry so flourishing as at Arcachon.

The "fattening" of oysters forms a separate industry in certain parts, the most important of which is in the district round the mouth of the River Seudre, near Marennes and La Tremblade. Here the land is flat and clayey and in it are dug series of shallow basins or "claires," into which open canals through which sea water enters during spring tides (Plate 108). During the intervening periods the water

remains stagnant and in summer becomes very hot and, by evaporation, very salty, conditions which result in a tremendous increase in the microscopic plant life, notably diatoms, which forms the ideal food for the oysters which are laid on the bottom of these claires. These grow and fatten at an exceptional speed and soon reach a remarkable size, when they are taken out of the claires and placed in stone tanks, known as "bassins de dégorgement," containing fresh, clean sea water in which they are left for several days in order that they may become thoroughly cleansed internally (Plate 108). The water is then run off, the outsides of the shells brushed clean, and the oysters are packed ready for transport.

It is in the claires at Marennes that the well-known green oysters are produced. These obtain their colour, which has become known as Marennin, from a particular diatom named *Navicula fusiformis* var. *ostrearia*. Although there is no discernible difference in taste, these green oysters are considered a delicacy in many places and command a high price.

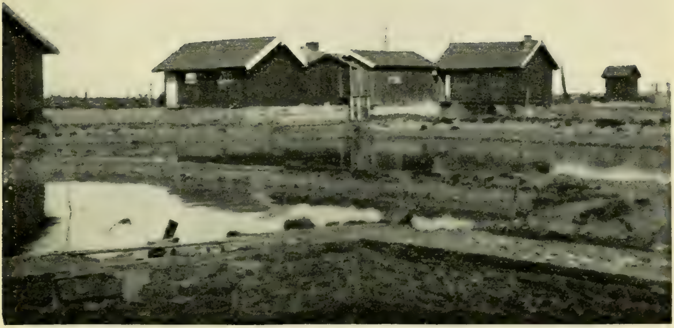
Originally the native oyster was exclusively cultivated in France but of recent years it has been almost completely ousted in the more southern beds by the Portuguese oyster of which the vast majority of oysters reared at Arcachon or fattened at Marennes now consist. The Portuguese oyster obtained its footing in France in a peculiar manner. A cargo of these oysters, considered to have gone bad, was thrown overboard near the mouth of the Gironde, but apparently some at least recovered, for a number of years later a large and flourishing bed of Portuguese oysters was discovered on the spot where the supposed rotten cargo had been thrown overboard. In the more northern beds, mainly on the north and south coasts of Brittany, the native oyster is still cultivated. It suffers however,

from being less hardy than the other, it cannot be reared on the shore so easily, while it is subject to mysterious diseases.

Unlike the Portuguese oysters which are all either of the male or female sex, the native oyster has the strange property of being alternately one sex and then the other ; the frequency of these changes depends on the temperature of the water, for example on the Danish beds they do not usually have more than one change of sex annually, but on the French beds they may have two or three. Since at each spawning the oyster in its female state produces millions of young, the potential production of spat where each oyster may spawn several times in a season, is almost inconceivable.

In Great Britain there is nothing to compare with the French oyster industry. There are many beds dotted along the coasts, of which the principal ones are situated near Colchester ; everywhere the oysters live in shallow water but are seldom uncovered in any number even at the lowest spring tides. They are usually collected by small rowing or sailing boats with the aid of iron dredges which are dragged along the bottom, the oysters being collected in the dredge bag which is usually made of steel links. Spat collectors are seldom used, but during the summer it is customary to throw great quantities of clean shell, known as "cultch" over the beds so as to provide good settling surfaces for the spat. Although the colder water round the British coasts renders oyster cultivation a more difficult problem than in France, there is no reason why the industry should not be greatly developed ; a fact which is fortunately recognized by the Ministry of Fisheries which has been conducting experiments on the artificial rearing of oysters at Conway, North Wales, for some years past.

Oysters are also cultivated to some extent in Holland,

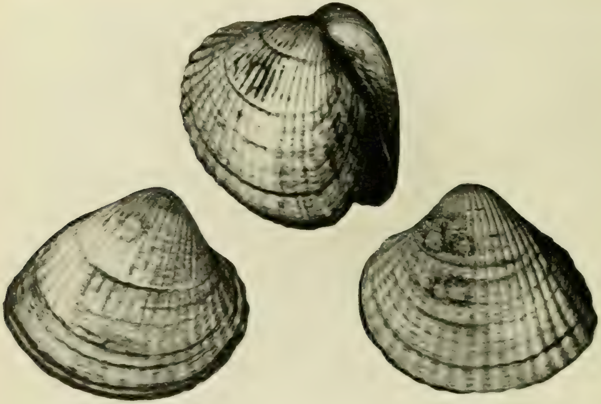


"Claires" at Marennes with oyster farms in the background, (p. 300).

Pl. 108. [?] 302.

"Bassins de dégorgement" at Marennes. (p. 301).

Portion of mussel bed, showing the dense crowding that may occur, $\times \frac{1}{5}$. (p. 304).



Pl. 109. p. 303.

The Cockle *(Cardium edule)*, $\times \frac{4}{5}$

Showing annual and disturbance rings on shell. (pp. 306, 308).

Belgium, and Denmark, while in Norway they are grown in special "oyster pools" at the heads of many of the fjords. These pools, which are natural, are almost completely cut off from the water in the fjords, and as a result, they become extremely warm in the summer, the microscopic plant life increases just as it does in the claires, and the oysters, which are usually kept in floating cages near the surface, grow at an unusual speed. Oysters have been cultivated for several centuries in Japan, where spat is collected, not on tiles, but on an ancient and efficient type of collector consisting of short lengths of bamboo on which the branches are left and which are stuck into the ground between the tide marks. The young oysters are left on the bamboos for from one to two years when they are detached and spread on prepared beds which are seldom uncovered except in spring tides. No artificial tanks are required and the process of cultivation is simpler than that adopted in Europe. In many regions along the coasts of the United States there are important oyster beds, some of which are in deep water and are fished by powerful steamers, capable of dredging immense numbers of oysters—up to 1,800 bushels per day. In Australia also oysters are cultivated, especially in New South Wales where spat is collected on stones, or on mangrove sticks which are stuck upright in the water. The oyster may then be matured, either laid on beds composed of shell or gravel, or else in wire netting trays.

Other Molluscs

After the oyster, the common mussel (*Mytilus edulis*) is the most important molluscan shellfish used as food in Europe. It is so common as to need no description. It is very abundant in sheltered parts of the coast, or in the mouths of rivers along the coasts of Britain. The natural

mussel bed, such as the one shown in Plate 109, consists, not of scattered animals, but of a solid mass of mussels of all sizes often six inches deep. The shell is not itself attached, but the animal discharges a series of fine, viscid threads known as "byssus," which are directed by way of a groove on the thin, extensible "foot" on to a convenient surface against which they adhere. They quickly harden in sea water and form an extremely strong attachment so that it takes the most violent storm to break up mussel beds although these are often found on mud flats or stretches of sand. So rich are these beds that it is seldom necessary to cultivate mussels, although it has been found by experiments on the Lancashire coast that small, stunted mussels from overcrowded areas speedily grow to large marketable size when transplanted to new areas. Many mussel beds are exposed at low water and the mussels collected by hand, but others are always under water so that they have to be fished from boats by means of dredges.

Mussels are, however, cultivated on the west coast of France in the shallow, muddy bay called Anse de L'Aiguillon. The system of cultivation employed dates back some seven hundred years to the chance which wrecked an Irishman called Walton, travelling on a small vessel containing sheep, in this region in 1235. He and some of the sheep—from which it is said certain valuable modern flocks are the descendants—were the only survivors and, in order to obtain a living, he tried to snare sea birds by means of rough grass nets fastened to stakes on the muddy shores. It is doubtful whether he caught the birds, but quite incidentally he discovered a more reliable food supply, for young mussels speedily covered his nets and, because they were raised above the mud in which they would otherwise have been smothered, they

quickly grew to edible size. From this strange beginning was elaborated the modern method of mussel cultivation on stakes interwoven with twigs, which now extend for great distances along the coast giving employment to the inhabitants of several villages. This is known as the " bouchot system," and the boucholeurs attend to their mussels at low tide, going out to the bouchots in small flat-bottomed boats called " acons " which are usually pushed along with the help of one foot which projects over the side of the boat and on which is worn a large sea boot.

Large bivalve molluscs known as Clams are extensively collected in North America where they are considered a great delicacy. There are two principal varieties eaten, one known as the soft Clam (*Mya arenaria*), and the other known as the hard Clam (*Venus mercenaria*) ; the same, or similar, animals are common on British shores but are seldom eaten, except locally. The soft clam burrows in mud or soft sand from which it has to be dug, and in a favourable area the population is extremely dense. In many parts of the north coast of America clam culture is a flourishing industry, young or " seed " clams being planted in favourable localities, from which the harvest is reaped in due course. In this way the soft clam, originally an Atlantic animal, has been introduced to the Californian coast where it has found ideal conditions and has spread over great areas round San Francisco Bay. The hard clam never appears to form such dense colonies as does the soft clam, and it has become comparatively scarce owing to the reckless way in which it has been gathered, and it is not yet cultivated to the same extent as the soft clam.

Of all Molluscan shellfish the scallop, with its rounded margins and radiating grooves, is perhaps the most beautiful, and the shell has been used for ornamentation and as a design since the beginnings of civilization (Plate 110). Even

the soft parts within the shell, which in the oyster are far from beautiful are here highly attractive with their areas of red, white and orange, marking the position of the reproductive organs, the muscle and the gills respectively. They are highly prized as food, two species being marketed in the British Isles, and many others in different parts of the world. Of the two former, one, the common scallop (*Pecten maximus*), is of considerable size, four inches or more in diameter and is considered a luxury, while the other (*Pecten opercularis*) is about a quarter that size and is often captured in large numbers off the south coast where it is known locally as the " queen " and finds a ready sale, being eaten raw like the oyster or else boiled.

The edible cockle (*Cardium edule*) is probably familiar to everyone. A good average specimen (Plate 109) is about one inch long and has a rounded white shell covered with small protuberances which enable it to grip the sand in which it lives. It is an extremely common shellfish usually living between tide-marks and is frequently found where there is a stretch of sand sheltered from currents and from the full force of the sea. Although it normally lies buried in the sand so that one end of the shell is just flush with the surface yet it can move about, either in the sand or on the surface, by the help of a muscular " foot," a wedge-shaped organ which is thrust out from between the two halves of the shell. Like all bivalve molluscs, cockles live on micro-organisms in the sea water and not on anything which they may obtain from the sand ; and as a result, if there is sufficient of the right kind of food in the water, the sand may be literally packed with cockles lying " cheek by jowl." It has been estimated that a single bed of some 320 acres in South Wales contains a population of about 462,000,000 cockles ! The young cockles spend a short period swimming freely in the sea before they settle down

to the quiet, sedentary existence they are henceforward to lead. At this stage they are spread far and wide by tides and currents, settling wherever they find a suitable bottom; and in some places there are special areas of soft oozy mud, quite distinct from the surrounding sand, which provide ideal nurseries for young or "seed" cockles, which form a compact layer just beneath the surface. As they grow, the boundary of the nursery extends on all sides over the surface of the sand but in the centre, where there is no possibility of further extension, the surplus population is forced to the surface whence it is largely carried away by currents, part to assist in the restocking of the sandy beds, and part to destruction. Cockles have the common enemies of all such shellfish; they are eaten by starfish, bored into by dog-whelks, and, especially in their younger stages, eaten by gulls, and probably also by flat-fish which swim over the beds when the tide is up. Owing to the exposure of the sandy beds, frost in winter or great heat in summer are both fatal to the cockle. Storms and currents also do great damage, the former by throwing the cockles above high-water mark and the latter by washing them from favourable to unfavourable localities.

The most important cockle industries in Great Britain are in the Wash, the Thames estuary, Carmarthen Bay, and Morecambe Bay. The cockles may be scraped up by hand, or may be dug, but more often short-handled rakes with large teeth or scrapers consisting of sickle-shaped pieces of iron are used. It is customary in the Morecambe Bay fishery to tread the sand with bare feet so as to bring the cockles to the surface, while a wooden frame with a base board which rests on the sand, known as the "jumbo," is used to force the animals to the surface in some parts of Lancashire. After they have been gathered and collected in heaps the cockles are washed and then riddled through

sieves the mesh of which is determined by local bye-laws, and only those animals which do not pass through the meshes are allowed to be sold, the smaller ones being replaced on the beds. They are seldom sent alive to the markets, but are usually boiled, often in iron vessels over extemporized fireplaces on the sea shore. At Leigh-on-Sea in the Thames estuary, the centre of one of the largest cockle industries in the country, the cockles are arranged in iron trays which are then placed in ovens the doors of which are clamped, and the cockles then sterilized by turning on steam for about five minutes at a pressure of from twenty to forty pounds. As a result of this process the soft parts come away from the shell from which they are separated in large riddles which are swung backwards and forwards until all the soft parts have dropped through the meshes. The meat is then washed in fresh water and dispatched to the market, either immediately or after pickling in salt or vinegar. The shells are often ground down to form grit for poultry.

It is possible to judge the age of a cockle by examining its shell, which is not added to regularly throughout the year but, owing to the greater abundance of food and warmer conditions, at greater speed during the summer than in the winter. This difference in the rate of growth of the shell is indicated by well-marked " winter " rings and these have only to be counted to reveal the age of the animal (Plate 109). This method is not, however, always accurate because the growth of the cockles which has been disturbed in any way—dislodged by storms or thrown too far up the shore—is checked and " disturbance " rings, not distinguishable from winter rings, are produced. Since young cockle may extend the edge of their shells at the rate of one to one and a half millimetres per week it is easy to see how a few days' disturbance may interfere

Pl. 110. X 308.

Scallop Shells. (p. 305).

1—6. Queens *(Pecten opercularis)*, showing various colours.
5. With acorn-barnacles attached. 7. Scallop *(Pecten maximus)*, · ½.

Mussel Purification Tanks, Conway.

Spreading the Mussels. (p. 311).

Pl. III. X 309.

Washing Mussels in Purification Tanks, Conway.

with the even production of the shell. Mussels and other bivalves show similar "disturbance" rings but not always winter rings. Oysters increase their shells by sudden bursts of activity, depositing a broad but very thin layer of new shell round the edge at a single operation. This thin layer is called a "shoot" and quickly thickens and hardens. The number of "shoots" per annum varies, but in this country appears to be between two and four, each of which in an oyster of two to three inches in depth may mean an increase of about one-third of an inch all round the edge. The variable number of these "shoots" makes it quite impossible to judge the age of an oyster unless the local conditions are very well known.

Hitherto all the molluscs we have considered have been bivalves, but there are also a number of univalve molluscs, marine members of the snail family, which are used as food. Of these perhaps the periwinkles (*Littorina*) are the most important. They are common on rocks and stones between tide-marks from which they are easily gathered at low tide. They are usually boiled before they are eaten. The common whelk (*Buccinum undatum*) is much larger than the periwinkle though in other ways very similar. It is not very common on the shore but is taken by dredging and to some extent in pots. It has a strong white or yellowish shell, good sized specimens being some four inches long by two and a quarter inches broad. The animal within is correspondingly large, but the flesh is close and tough. Nevertheless, after boiling or pickling, they are eaten in tremendous numbers. The common limpet (*Patella vulgata*) is also collected and sold as food in many parts, but is extremely tough.

Molluscan shellfish provide a valuable source of food. Owing to the fact that they store great quantities of glycogen or "animal starch" as well as fat and protein,

they form a complete food in themselves, and an oyster has been compared in food value to a glass of milk. Moreover, under the right conditions, great numbers can be cultivated in comparatively small areas. Although not yet applicable to the true fisheries, aquiculture or farming of the products of the sea, has been shown to be a perfectly practicable proposition when applied to shellfish, the collection and sowing of the "seed" followed by care and attention during growth, resulting in a rich harvest, some idea of which will be gained from the following extract from an official report of the Ministry of Agriculture and Fisheries.

"It has been calculated that an acre of the best mussel ground will produce annually 40,000 lbs. of mussels, equivalent to 10,000 lbs. of mussel meat with a "fuel" value of 3,000,000 calories and a money value of about £250, and this at the cost of practically no capital expenditure and only such labour as is involved in transplantation to prevent over-crowding, and to secure the best conditions for growth and fattening. No known system of cultivation of agricultural land can produce corresponding values in the form of animal food. The average yield in beef of an acre of average pasture land is reckoned to be 100 lbs., equivalent to 120,000 calories and valued at, say, £7 10s. The yield of rich fattening pasture may be as high as 190 lbs., equivalent to 480,000 calories, and valued at, say, £14."

Purification

Unfortunately, there is one great drawback to the consumption of shellfish; the risk of bacterial infection. Oysters and mussel beds are often situated in estuaries many of which are badly contaminated by sewage brought down from towns further up stream. Any bacteria there

may be are liable to be taken into the stomachs of the shellfish which feed on any small particles in the water, and, though they are themselves unaffected, they may in this manner become a medium for the dissemination of typhoid and other pathogenic bacteria. Rigorous regulations forbid the sale of polluted shellfish but the risk of disease has been an important, and in the past, not unjustified reason for the undoubted prejudice against the use of shellfish as a food.

The best preventive measure would undoubtedly be to forbid the discharge of unpurified sewage in the neighbourhood of shellfish beds, but unfortunately this is quite impracticable at the present time. The only alternative is to purify the shellfish and this has been done with striking success at Conway, where the extensive mussel beds had led to the development of a considerable industry, the collected mussels being sold to the large Midland towns. After an adverse bacteriological report the sale of these mussels was prohibited in 1912 and many men were thrown out of employment so that the Corporation of Conway started investigations, later taken over by the Ministry of Fisheries, in the hope of finding some method whereby mussels could be purified. This has to be carried out under artificial conditions and for this purpose large concrete tanks were constructed and, after lengthy experiments, a simple but eminently successful method of purification was devised. The mussels, which are brought to the tanks in sacks by the fishermen are spread two deep on wooden grids in the bottom of shallow tanks, as shown in Plate 111, and thoroughly hosed so as to clean the outside of the shells. Sea water, which has been sterilized by the addition of chloride of lime, any free chloride being converted into common salt by the action of sodium thiosulphate, is then run in by gravity from storage tanks, and the mussels

are left in this water for one day. They quickly open their shells and discharge the contents of their stomachs including any bacteria they may contain, while at the same time they take in sterilized water. This water is then run off and the tank filled with fresh sterilized water for a similar period to make sure that the mussels are thoroughly cleansed internally. Again the water is run off and, last of all, the shells are sterilized with chlorinated water, the cleansed mussels being then packed in sterilized bags and sent off to the markets. This system of cleansing was begun on a commercial scale in 1916, and has proved a complete success, the flavour of the mussels is not impaired while there have been no further complaints of pollution, and the mussel fishery has regained its original importance. As expenses have to be met by a fixed charge for each bag of mussels cleansed, only the larger mussel fisheries can be treated in this way owing to the expense of erecting the cleansing tanks, and consequently many of the smaller fisheries which have been condemned cannot be treated in this way, but a second cleansing station has recently been erected at Lympstone on the River Exe in Devonshire. Mussels are only collected during the winter, and during the summer months the tanks are used for experiments on the purification and breeding of oysters.

Oysters do not take in bacteria quite so readily as do mussels, but when they are polluted are more difficult to purify, owing to the fact that unless the water is over a certain temperature they refuse to open their shells and so become sterilized internally. It is probably only a question of time before a suitable method of purification is devised when it will be possible with perfect safety to eat oysters from many localities now banned on account of pollution. The shellfish industries are in their infancy

and are capable of almost unlimited expansion with the certainty of producing great quantities of highly nutritious food.

It would obviously be of the greatest value if large supplies of spat oysters could be produced under artificial conditions for subsequent laying on the commercial beds. To this end a series of experiments are being carried out at Conway during the summer months. Adult oysters are placed in the tanks under a series of different conditions and the effect of various kinds of food on the production of young and the settling of spat studied. So far, the experiments have not been very conclusive but good results have been obtained by placing large amounts of brown seaweed in the tanks, these produce great numbers of minute " spores "—or seeds—on which the young oysters readily feed. Temperature has an important effect on the spawning of oysters, the higher the temperature the more frequent the changes from male to female in the native oyster, and so the more frequent the production of batches of eggs which are incubated within the shell of the parent for some days before they swim out into the sea. At first they are whitish and the parent is said to be " white sick," but later, when the young begin to feed, they turn darker and form a greyish mass about the gills of the " black sick " parent. The Portuguese oyster does not incubate its young which develop from the earliest stages in the sea. It has been suggested that they might be established in this country by obtaining ripe adults, opening them and scattering the reproductive products in the water over the beds, where the young would, it is thought, settle and grow. This process would have to be repeated each year because, as we have seen, the water is here too cold for this oyster to spawn naturally.

Crustaceans

Of the edible Crustacean shellfish the largest and most valuable are the European and American lobsters (*Homarus gammarus*, and *Homarus americanus*). The former (Plate 113) live in comparatively shallow water just below low-water mark and are especially common where there is a rough hard bottom, in the crevices of which they find shelter, darting out at the approach of food. They occur along the coasts of Europe from the Mediterranean to Norway but the most important lobster fisheries are found in the more Northern regions especially Norway, Scotland, England, Ireland, and Heligoland, the usual methods of capture being by means of traps known as " Lobster pots " or " creels." Some of these are of wickerwork, rounded with a flat bottom and a funnel-shaped opening on the top—rather like a safety inkwell—so that the lobsters can easily enter but usually fail to find their way out ; others are in the form of a half-cylinder with a framework of wood and netting. These traps are usually fastened together with rope having cork buoys at the ends, and before they are placed in position are baited with pieces of stale meat. Fine specimens of this lobster may attain a weight of ten pounds, and specimens of fourteen pounds have been caught, but the American lobster, almost exactly like the European species in other respects, grows much larger and may attain a weight of twenty-three pounds. It is found on the Atlantic coast of North America from Labrador to New England, and the collection and canning of lobsters forms an important industry in Canada, Newfoundland, and New England. In many regions lobsters have been caught in such numbers as seriously to affect the fisheries, and protective measures of various kinds have been tried ; in some places it is illegal to take from the

sea lobsters which are below a certain size or females which are carrying spawn, or are " in berry."

A few words about the important lobster fishery in the Hebrides may be of interest. The lobsters are collected by fishermen in many parts of the islands and stored in large boxes, with holes to allow free access to water, which are moored in the sea in which they lie just awash. When sufficient numbers have been collected they are packed in boxes and sent away to the market, usually Billingsgate. It is important that the packing should be done with great care as only living lobsters are paid for by the purchaser. Of recent years the efficiency of the industry has been greatly increased by the activity of a firm which has established a receiving and storage pond on the Island of Luing, about fourteen miles from Oban. The pond has been made by erecting granite dams at either end of a narrow channel between two islands, a constant flow of sea water is ensured by means of gratings in the dams while sluices enable the pond to be practically emptied at low tide. One hundred thousand lobsters can be stored here—half as many again if necessary—the animals being collected by agents of the company from the fishermen who thus get a good price for their catch without the risk of losing them on their way to the market. Similar storage ponds for lobsters have been established for many years along the coasts of Brittany. The packing station is on Kerrera Island only two miles from Oban where there is a sheltered bay in which the lobsters are confined in large wooden rafts each capable of holding about a thousand, until needed for packing. In the latter process, bracken or fern, which is better than the seaweed or sawdust originally used, is employed, the boxes being lined with paper to keep the lobsters within from extremes of temperature. Since it is the presence of water in the gill chamber which is responsible

for the animals remaining alive out of water, care has to be taken not to squeeze this region during packing.

In the English Channel the place of the lobster is to some extent taken by the handsome Spiny or Rock Lobster or Crawfish (*Palinurus vulgaris*), which differs from the lobster in its larger size, its brown beautifully sculptured shell and lack of large claws (Plate 114). It is seldom eaten in England but is regarded as a great delicacy in France, where it is known as "Langouste." Other kinds of Spiny Lobsters are used as food in different parts of the world such as California, South Africa, Australia, New Zealand, and India. In the North Sea and off Norway a much smaller animal, the Norway Lobster (*Nephrops norvegicus*), is caught (Plate 113). This has long slender claws and is orange coloured with red and white markings. It generally lives on a muddy bottom and inhabits much greater depths, usually from thirty to sixty fathoms, and has to be captured by trawling, being often caught in large numbers by steam trawlers on their return journey to the northern fishing ports of Great Britain. It is useless if caught on the outward journey because, unlike the ordinary lobster, it cannot be kept alive and sent to the market fresh but has to be boiled almost immediately after it is caught. It was once fished in large numbers in the Irish Sea, those sold in London markets being known as "Dublin Prawns." In the Mediterranean it is extremely plentiful in the Adriatic and is sold in the Italian ports under the name of "Scampo."

In the British Isles the edible crab (*Cancer pagurus*) comes second to the lobster in importance among the Crustacean shellfish. It lives in shallow water along rocky coasts and in regions of submerged valleys under much the same conditions as the lobster and is caught in pots in the same way. Fine specimens may weigh as much as twelve

pounds and be over ten inches broad. No other crab is eaten to any extent in the British Isles, although the shore crab used to be sold in great numbers and is still eaten on the shores of the Mediterranean and on the Atlantic coasts of France, where the large Spider Crab (*Maia squinado*) is also eaten in spite of its extremely thick shell. The Blue Crab (*Callinectes sapidus*), one of the swimming crabs, takes the place of the British edible crab along the Atlantic coasts of North America, where several other crabs are also eaten; in the East Indies also various kinds of swimming crabs are used as food.

The shrimps and prawns include a number of smaller Crustaceans which are collected in large quantities for food. Of the prawns the largest sold in this country is *Leander serratus* (Plate 117) which is often four inches or more in length with a fine serrated rostrum. A second common prawn, distinguished from the common prawn, Leander, by the name "Pink Shrimp," is *Pandalus Montagui*, an exceptionally handsome crustacean, while another species of the same genus (*Pandalus borealis*) is imported from Norway. This is an exceptionally fine prawn often six inches long, which, unlike the other prawns we have been discussing which live in shallow water, is found in the fjords at depths of from thirty to sixty fathoms. The growth of this fishery was the result of scientific research of the Norwegian Fishery Department which revealed its hitherto unknown presence in the deep water, and showed that it could be caught on a commercial scale by means of special trawls, with the result that an important fishery of these "deep-water prawns" was established. Many other kinds of prawns are caught in different parts of the world and attempts have been made to send frozen prawns from Queensland to England.

The common shrimp (*Crangon vulgaris*) is one of the

most abundant of British Crustaceans (Plate 117). It is found round the coasts where the bottom is sandy—unlike the prawns which prefer rocks—and is very difficult to see on account of its greyish-brown colour and habit of burying itself in the sand. The catching of shrimps in large nets attached to long handles which are pushed over the surface of the sand in shallow water forms an industry of some importance in many parts of the country. In some regions a large type of shrimp-trawl is drawn through the water behind a horse and cart.

Few of the lower types of Crustacea are eaten, but the Barnacles form an exception. One of the sessile barnacles (*Balanus psittacus*) which is found on the Chilean coast, where it attains a length of about nine inches and a breadth of three inches, was reported by Darwin to be "universally esteemed as a delicious article of food," and another large barnacle is eaten on the coasts of British Columbia, while a stalked species (*Pollicipes cornucopia*) is eaten by the maritime population of Brittany and Spain. Another use for them has been found in Japan, where a species of sessile barnacle is collected on bunches of bamboo (in very much the same manner as oyster spat), which after some three months are removed and the barnacles beaten off and sold as manure.

CHAPTER XV

Fishery Research

To a naturalist the engrossing work of unravelling the many mysteries of life in the sea and the quest for information to enable a clear picture to be gained of the life stories of the animals is all sufficient. But in these days of applied science the naturalist is also called upon to utilize his knowledge to help the many industries which are dependent on the products of the sea. By far the most important of these products are those fish that are eaten by man—under the term edible fish are generally included both the true fish and the shellfish which consist of crabs, shrimps and oysters, etc.

There can be no hard and fast line between oceanography and fishery research, because all of the widely ranging problems attacked by the oceanographer will be found to have some indirect bearing on the lives of the fishes living in the sea. Fishery research is, rather, a branch of oceanography, and its main concern is an attack on the problems directly connected with those fish which form the chief supplies of food from the sea.

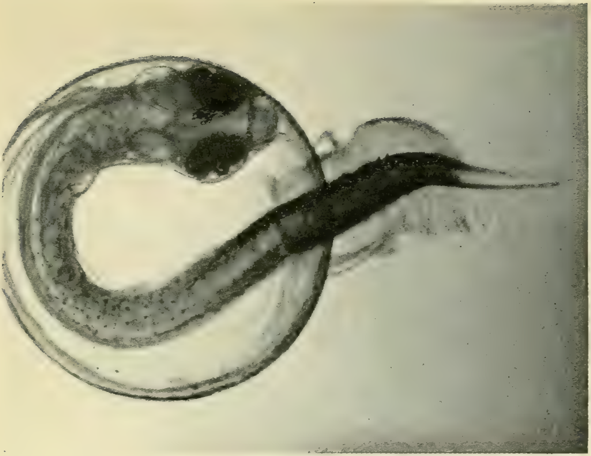
The foundations for the application of science to the fishing industry must lie in a complete and intimate knowledge of the life-history and habits of each fish. It will perhaps enable the reader best to grasp the methods and aims of modern fishery research if we describe how our present knowledge has been gained of two fish, such as the herring and the plaice, which differ widely in their habits. Both of these fish are of the greatest importance

to the fishing industry, the herring, indeed, being one of the most important of all fish from the waters on the north-eastern part of the Atlantic. The plaice make up a large part of the catches of the trawlers in the North Sea while the pursuit of the herring constitutes that great drift-net fishery which takes place around our coasts chiefly in the late autumn and winter. This distinction points at once to a fundamental difference in the behaviour of these two fish. The plaice which are captured by the trawls that scour the sea floor are bottom-living or demersal fish, while the herring, as their mode of capture suggests, live, for considerable periods at any rate, in the water layers above the bottom and are pelagic.

In studying the life-history of a fish it is best to start right from the beginning and watch the growth and movements of the individual from the time it is first brought forth by the parent fish as an egg.

Let us, therefore, put ourselves in the place of the early naturalists, the founders of fishery research, and imagine that we must set out to find the eggs of the herring and the plaice. We should immediately say, " How can we find them if we do not know what they are like to look at ? " This brings us to the very first step in the study of the life of a fish. The eggs when discovered must be accurately described and figured so that those who come after us may know at once what to look for.

Towards the end of the nineteenth century a controversy arose as to whether the advent of the steam trawler might not have a harmful effect on the sea fisheries by destroying in large quantities the eggs of the fish as the heavy net was dragged over the bottom. In the year 1864 the great Norwegian naturalist, Prof. G. O. Sars, discovered large numbers of eggs drifting in the surface water layers well above the bottom, and was able to show that these were



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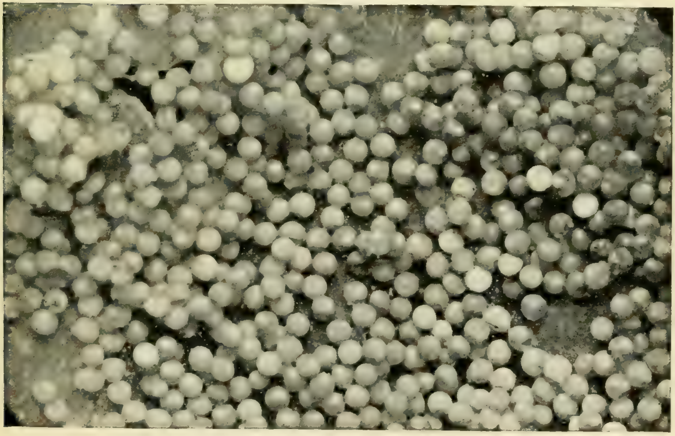
Plaice, hatching from egg, × ca. 25. (pp. 80, 324).



Pl. 112. *X* 320.

Eggs of Herring, ×2. (p. 321).

Pl. 113.

The Common Lobster *(Homarus vulgaris)*, $\times \frac{1}{4}$.
(pp. 35, 63, 67, 316).

X 321.

The Norway Lobster *(Nephrops norvegicus)*, $\times \frac{1}{3}$. (pp. 67, 316).

the eggs of the cod. This discovery stimulated the search for the eggs of other fish and it has since been found that, with only one exception, all our food fish have these drifting eggs. This early piece of fishery research immediately showed its practical value ; for, when the discussion arose about the necessity of putting restrictions on steam-trawling because of the supposed destruction of eggs, the scientific advisers were able to show that no such danger existed.

It has been said that there was one exception to the rule that our food fish have pelagic eggs. This exception is the herring, whose eggs (Plate 112) stick in clumps to the bottom (see page 80). In this case however there is little risk of their destruction by the trawls, because the eggs lie well down in the crevices between the stones on the rough ground on which they are laid, apart from the fact that the rough grounds on which the herring spawn are generally so rocky and strewn with boulders that they are unsuitable for trawling.

The eggs of the plaice and the herring having been accurately described and identified by means of artificial fertilization and by hatching, we can now proceed in our search for the spawning grounds of these two fish. There are two obvious ways of searching for these localities, firstly by seeking for the eggs themselves and secondly by finding from the statistics of the fishing industry at what places most of the fish containing ripe roes were caught. The last method obviously involves the least trouble (given the necessary statistics), but it has the disadvantage that the results are only approximate, as there is no evidence that the fish would have actually spawned where they were caught since they can swim a considerable distance in a short space of time.

Let us then consider the first method. Having roughly marked out the spawning region by means of the statistical

method, it is necessary now to put to sea to these grounds. The plaice egg we have said is pelagic and drifts about in the water layers above the bottom. To catch these eggs therefore a tow-net must be used. The area to be searched is divided up on the chart into a number of small sections in each of which a point or "station" is marked, at which hauls with the tow-net are to be made. Generally, when a research vessel is on a "plaice-egg cruise," a vertical tow-net is used; that is, a net which is hauled up vertically through the water from bottom to surface. The depths being known, it thus becomes possible to compare with accuracy the actual numbers of eggs caught in different localities. At the end of the cruise the numbers of eggs taken at each station are marked out on the chart and contours drawn through the stations where approximately the same numbers of eggs were caught (Fig. 61). In this way, if the whole area in which the eggs were actually present has been studied, a map should be produced showing the largest numbers of eggs caught near a centre, the numbers becoming less and less the further one goes from this centre. Now the worker, who was counting the eggs, at the same time made notes as to the stage of development of the young fish within the egg. By the use of drift bottles and current metres, as described in a previous chapter, a rough measure can be obtained of the movements of the water in the regions examined. It has been worked out how long it takes a plaice egg to develop under different temperature conditions, and the temperature of the water being known the investigator can immediately reckon how many days have elapsed since the actual spawning of the eggs which he has taken. Knowing also the rate and direction of the water movements he can lay his finger on the spawning grounds.

Other methods need to be resorted to in a search for the

spawning grounds of the herring, since its eggs are laid on the bottom. In this case, besides gaining information from the actual catches of herring, an examination of the stomach contents of other fish becomes advantageous. It is known that the haddock will greedily devour herrings' eggs, and the occurrence in the trawl of so-called "spawny

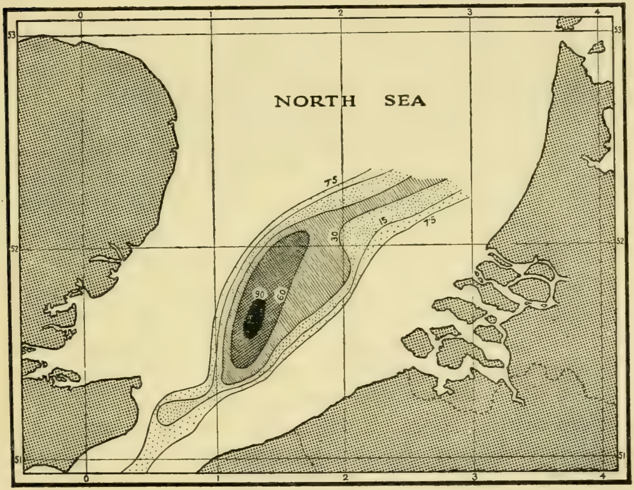


FIG. 61.—Chart showing distribution of plaice eggs in the North Sea in December, 1910. The figures show the numbers of eggs per square metre surface. (After Buchanan-Wollaston.)

haddock" crammed with herring spawn is a sure indication that the spawning grounds are not far off. An actual search for the eggs is far less fruitful, owing to the fact that they lie in the crevices between stones and are rarely taken in the trawl. On occasion they have been searched

for by means of the "grab" mentioned on page 263, but here again the chances are small of the instrument picking up a sample of the bottom from exactly the right spot.

Let us now trace the life story of the plaice in the southern North Sea. Research carried out on the lines indicated above shows that the mature plaice gather into a region some little way off the Dutch coast: here the eggs are discharged and drift freely in the water for about a fortnight, at the end of which time they have been carried by currents further north and considerably nearer the coast. From the eggs hatch those little symmetrical larvae mentioned in a previous chapter (Plate 112). The movements of the plaice can be followed by making catches with a very large coarse-meshed tow-net. It will be found that by the time they are about three-quarters of an inch in length they are being drifted very near to the coast. When they have reached this size they suddenly disappear from the tow-net catches. Their metamorphosis has taken place, that is the left eye has moved over to the right side of the head and the fish has assumed the typical adult characters. At this stage the fish seeks the bottom. It must then be sought with the aid of a fine-meshed trawl, such as the shrimp-trawl. A search will reveal that the young plaice have moved into the shallow water covering the sandy flats that occur all along the Dutch coast. Here fish between one and two inches in length can be caught in immense numbers. When the plaice are of this age they can often be found in the sandy pools left uncovered by the tide. As an illustration of this a photograph is given in Plate 115 of such a pool in the Gannel Estuary at Newquay, Cornwall. Two of us fishing in this small pool for just under an hour with small prawning nets early in June captured the forty young plaice shown in their natural size on Plate 116. There were probably still many left in the pool

as the meshes of the nets used were rather large and the smaller specimens could slip through with ease. Thus we see how the coastal waters of Holland can form a nursery ground for a very great number of the stock of plaice in the North Sea. This discovery is of great economic importance. It is on the survival of these fish that the future stock of large plaice depends. Immense damage is, however, done on these grounds by long-shore fishermen seeking other fish. So important an aspect has this assumed that it has been seriously urged that at the time the young plaice are there the grounds should be completely closed to trawling fishing craft.

From a size of four or five inches onwards we are dependent on the statistics of the landings of fish for information as to their general distribution. But while these figures will give information as to their distribution they tell us nothing of the movements of the fish or of their subsequent growth. It is here that the system of marking the plaice has proved invaluable. A small piece of silver wire is pushed through the back of the fish and on either end of it are attached small ebonite discs bearing a number. The fish thus marked are then measured, and their length, together with date and place of capture, is inserted in a book opposite the number corresponding with that on their discs. The fish are then liberated.

Fishermen are notified that for each marked fish returned to headquarters they will receive the market price of the fish and a shilling for the disc. When a fish is recaptured it is once more measured and, on comparing its length and date and place of recapture with the original details for the fish bearing that number, one can immediately tell how much it has grown and how far it has travelled since the day it was marked (Plate 115).

In order to study the population of plaice in a large area

like the North Sea it is necessary to be able to tell the age of great numbers of fish. Fortunately the plaice carries its own age indelibly written upon it. Situated in a cavity just behind the brain are two small white bones. These lie loose in the ear sac and enable the fish to regulate its balance in the water, just as the semicircular canals in our ears provide us unconsciously with a means of keeping ourselves upright (Plate 118). Examination of these ear bones, or "otoliths," shows that they possess alternate light and dark concentric rings, similar in a way to those on a cross section of a tree trunk. It has been proved by a study of the earbones of marked fish that these rings correspond to the summer and winter growth of the fish.

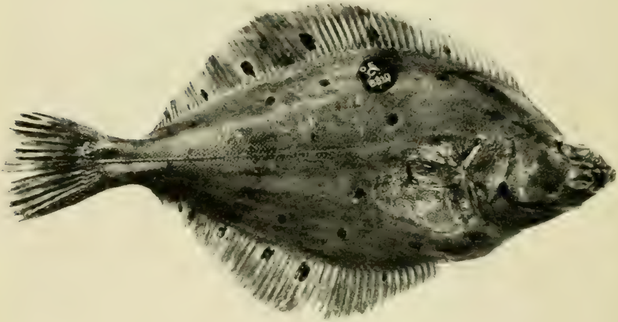
Of great importance in the study of the life-history of a fish is a knowledge of its food and feeding habits. The method of finding out the chief food eaten is a very simple matter and merely consists in opening the stomach and examining the contents. When a very large number of fish have been thus examined over a period of two or three years a knowledge is gained of the most common kind of food for the different sized fish and of any changes in the diet that may occur during the seasons. Having discovered the food the next problem is to find out what its distribution is in the sea, because where the food is there we should naturally expect to find the fish that feed on it.

Now, the adult plaice is a bottom feeder ; that is, it makes its meals of animals that mostly live on the sea floor and while very many animals are included in its diet, the most important item by far for the adult plaice in the North Sea is a small shellfish known as *Spisula* (Plate 118). To examine the distribution of this sort of food the grab is used and the actual numbers of animals caught in a given area counted, so that, by making observations at stated intervals over a large region, a chart may be drawn

Pl. 114. Y 326.

The Rock Lobster or Crawfish *(Palinurus vulgaris)*, × $\frac{1}{3}$. (pp. 67, 316).

Pool in Gannel Estuary, Newquay.
Where young plaice in Plate 116 were caught. (p. 324).



Pl. 115. *Y* 327.

Marked Plaice, × ca. ½. (p. 325).

up showing the relative frequency of the animals from one spot to another. Such research has been carried out in many localities and it has been found that compared with other places the Dogger Bank is surprisingly rich in these shellfish. The effect of this abundant supply of food has been shown in a very striking manner. A large number of small plaice were caught off the Dutch coast and marked. Of these one half were liberated again at the spot at which they were caught, but the other half were kept on board the research ship in special tanks and transported up to the Dogger Bank, where they were allowed to go free. After a time these marked fish began to be returned by the fishermen. Examination revealed the fact that those that had been liberated on the Dogger Bank grew very much faster than those that had been returned to their place of capture off the Dutch coast. This great growth is to be correlated with the great amount of food present on the Dogger grounds compared with that of those of the Dutch coast.

These results have suggested that it might be a practical proposition to transplant large numbers of fish and so increase the resources of the North Sea. There are unfortunately one or two obstacles in the way, such as a decision as to who should bear the cost of the transplantation, and the expense necessary for patrolling the grounds immediately afterwards to prevent too eager fishermen from at once fishing up all the newly arrived plaice.

One of the most instructive results of these and similar marking experiments is to draw attention to the grave risk that is now being incurred of depleting the stock of plaice in the North Sea. Within a year of liberation over a quarter of the marked fish are recaught, 250 to 300 out of every 1,000 marked plaice being recaptured. This

may be taken to mean that a quarter of the catchable plaice are taken out each year—that is those fish which are large enough to be retained by the meshes of the net. At first sight one does not think this to be really possible. We say, the sea is so vast that the efforts of man can have no effect upon the fish population. But when we realize that a fish like the plaice inhabits only the comparatively shallow water, and that this water is of a very limited extent compared with the deep oceans, and when we are told that the area covered by the nets of all British steam trawlers in the year 1926 was about 108,000 square miles and the area of the North Sea itself being only about 130,000 square miles, we realize that the chances in favour of the plaice are small indeed. Especially is this so since the trawling area is not distributed all over the North Sea, but is concentrated on certain grounds where the plaice are most abundant.

Let us now turn for a while from the problems of the plaice and follow the study of the life-history of that pelagic fish, the herring. Earlier in this chapter we have described the general methods of locating the spawning grounds of the herring, by noting the presence of ripe fish, by searching for eggs on the bottom with the grab, and by seeking for "spawny" haddock.

A study of the distribution of these spawning grounds shows that the herring choose out regions in the close vicinity of the coast and especially of the estuaries of rivers.

It is next necessary to follow the movement of the young herring as soon as they have hatched from their demersal eggs. The baby fish very soon after hatching make their way up from the bottom into the water layers nearer the surface, and here they may be caught by means of tow-nets in the same way as the young plaice.

But when the herring is about three or four months old

it has reached a length of about one and a half inches and can swim too rapidly to be captured by the tow-net. At this stage the fish congregate in shoals and their movements become very hard to follow. We have no really efficient instrument for catching them in the open sea, but they may be caught by fishing off sandy shores and in estuaries by means of very fine-meshed seine nets. In fact recent research points rather to the fact that it may not be necessary to search in the open sea for the herring at this stage in its life-history, for it is beginning to be realized that the numbers present in the estuaries are very great and probably quite sufficient to give rise to the large supplies of adult herring caught by the fishermen in the open sea. At certain seasons of the year, for instance, the whitebait that abound in the Thames estuary consists almost solely of young herring (Plate 119). When the herring reaches a length of three or four inches it probably leaves the estuaries, and little is as yet known of its movements until it grows to a size large enough for capture by the nets. In the case of quick-growing fish probably the end of the second year is the time at which they are large enough to appear for the first time in the net catches ; the fish would then be about six inches in length. But more usually the herring are not large enough to be taken in the drift nets until they are three years old, or at any rate in their third year.

It is difficult to follow the movements of the adult fish. They are too delicate to be marked like the plaice. Any one who has handled a fresh herring knows how easily the scales come off and if the fish is returned to the water with many of its scales removed the large surface of bare skin thus exposed soon becomes infested with bacterial and other parasites and in a very short time the fish succumbs. It is therefore practically impossible to mark the herring with any hope of their survival.

The fishermen's catches tell us at any rate that when the spawning season arrives the herring congregate in the coastal water. It is probable that after the completion of spawning they move out from the coasts into deeper water, as is testified by the fact that they can be captured in large numbers in the trawls in the deep waters off the Bristol Channel, the Smalls Grounds.

We have mentioned previously (page 280) the former belief that after spawning all the herring retired to the Arctic Ocean to recuperate, whence they once more moved down along our coasts in the following year to spawn. This is generally now considered to be an incorrect view, and it is thought that when not spawning the herring congregate into the deeper off-shore water. This has led to the opinion that there are definite "races" of herring which keep more or less in their own regions. Thus there are the Baltic herring, a race of small sized fish; the Channel herring from the English Channel; the Iceland herring, and others. It has indeed been found that the herring coming from widely separated localities exhibit certain differences in their structure. Notably is this the case in the number of vertebræ the fish possess in their backbones. It is generally the case that the herring from the coastal areas, where the water is of low salinity, have fewer vertebræ on an average than those from more saline ocean waters. Thus, the Baltic herring have an average of between 55 and 56 vertebræ, those of the western end of the English Channel 56 to 57, and the Iceland herring between 57 and 58. By counting the vertebræ in large numbers of fish from different localities and studying the age of the fish from their scales, it appears probable that it may eventually be possible to trace roughly the movements of the various herring races.

When counting the herring vertebræ it is usual to bring

the fish up to boiling point in water so that it is just beginning to be cooked. The flesh may then be easily scraped from off the backbone, without the backbone itself falling to pieces. A much more rapid and clean method which may replace the older method, is merely to take X-ray photographs of the herring, when the vertebræ can be counted on the negative (Plate 120).

The scale of the herring is well suited for studying its growth rate, for the yearly rings containing broad and narrow bands, corresponding to periods of fast and slow growth, are clearly marked out on it (Plate 120). It is known that the scale grows in proportion at a corresponding rate to the body of the fish, and from the distance from the centre of the scale to the outer edge of each yearly ring can be calculated the size of the fish at the end of each year (see Fig. 62).

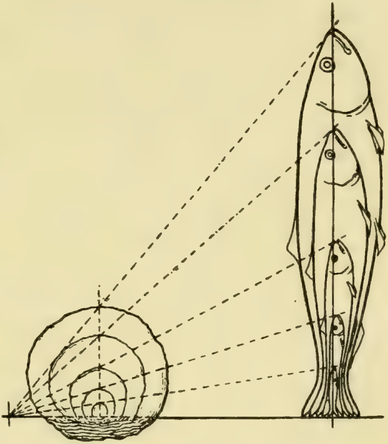


FIG. 62.—Diagram showing how the scale growth is proportional to the growth in length of the whole fish.

Examination of scales from large numbers of herring during the course of many years has thrown very interesting light on the age composition of the shoals of fish. It may, for instance, be found that in one year over seventy per cent. of the herring caught were six years old, the remainder being mostly four, five, seven and eight. The fact

that these six year old fish absolutely outnumber the fish of all other ages indicates that six years before there was a great survival of young herring, far and above those born in the years immediately previous and succeeding. That year is then known as a good "survival year," and it may be found that for several years the catches will be dominated by fish born then.

For many consecutive years Norwegian investigators studied the age composition of their shoals, and the domination of the catches by a single year-class derived from a good "survival year" is clearly shown by the following instance. In the year 1908 the 1904 year-class (i.e. fish born in 1904) appeared in large quantities in the catches. From that year until 1919 these 1904 fish were still predominant, by which time they were fifteen years of age. For eight years, 1909 to 1916, they had in fact practically supported the herring fishery industry; but in 1919 there appeared in the catches a new set of fish hatched in 1914, that is six years old, which nearly equalled the 1904 fish in numbers. Not until 1924 did the 1904 fish die out from the catches, and about this time the 1914 class was also on the wane, but in 1922 a new brood appeared which was still predominating in 1926 (Fig. 63).

Thus we are faced with the amazing conclusion that the main stock of herrings on which we draw may consist for several years of the production of a particular year's spawning, and the outlook for the herring fisheries will be serious if this stock is depleted before there has been another good "survival year" to keep the supply up to the demand.

It is one of the main aims of fishery research to find out what is the exact combination of conditions necessary to bring about a good "survival year," and this knowledge can only be gained by taking very full and detailed observations over a long period of years. With such knowledge it would

be possible to predict three years in advance when another large influx into the herring population would occur, because, as has been said before, it is generally three years before the herring has grown large enough to be captured by the nets employed by the fishermen.

This phenomenon has also been shown to hold good for other fish such as the haddock and the plaice. Indeed, it is only reasonable to suppose that it is the rule rather than the exception for each kind of fish to have both good and bad "survival years."

In the year 1923 unusually large numbers of baby haddock appeared in the catches of the ring-trawl made by the scientific staff of the Scottish Fishery Board. In consequence of this it was boldly predicted that in three

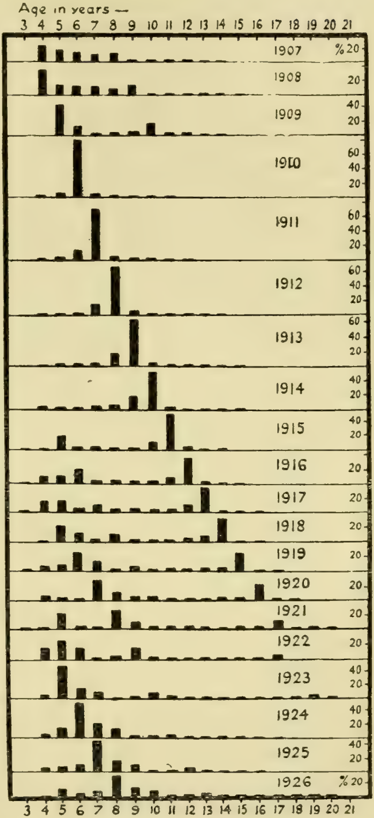


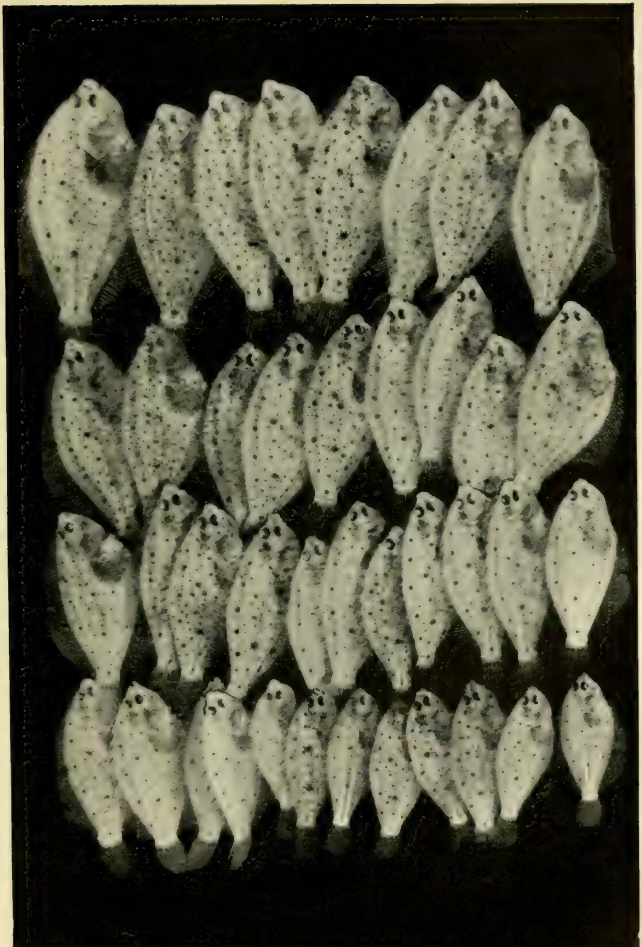
FIG. 63.—Diagram showing the percentage age composition of the herring caught off Norway each year from 1907 to 1927. The great preponderance of fish born in 1904 in the catches for many years in succession is clearly shown. (After Einar Lea.)

or four years' time there would be a very flourishing fishery. The prophecy was fully borne out. It is clear that such prediction must prove of value to the fishing industry as it will obviate an unnecessary glut on the market in the event of a coming good year, or direct attention to some more profitable fish before the lean year comes.

After making detailed observations of the temperature and saltness of the waters of the Danish coasts throughout a period of many years, the Danish Fishery investigators have discovered that there is a connection between the hydrographical conditions of the water and the mackerel fishery. As soon as the observations of the saltness of the water are known for March and April it becomes possible to predict whether the mackerel fishery taking place two months ahead will be good or bad. The presence of mackerel in this case is probably determined by the strength of certain currents flowing into the Baltic.

It is unlikely that, as yet, such a method will be possible in such waters as those of the English Channel. Conditions in the Danish waters are somewhat special owing to the admixture of fresh water from the Baltic Sea and salter water from the North Sea. Differences in the hydrographical conditions of the various water layers are there much more marked than we should expect to find in more open water such as the English Channel, where connections between these conditions and the movements of fishes are harder to find. This is not to say that they may not be found some day when our observations are more complete and the methods of making them more perfected.

Now a fisherman is essentially a gatherer of a harvest he has not sown. He goes out and catches fish from the sea but does nothing to increase the supply contained therein. What has happened in other cases where man has hunted without thought for the future? Whole seal popula-



Pl. 116. Y 334.

Young Plaice caught in one hour from pool shown on Plate 115.
Natural size. (p. 324).

Pl. 117. DEL. F.S.R. P 335.

1. Common Prawn *(Leander serratus).*
2. Common Shrimp *(Crangon vulgaris).*

Natural size. (p. 317).

tions have been wiped out; several species of whales have come dangerously near complete extermination and what were once flourishing whale fisheries practically no longer exist. And it seems certain that sooner or later there will be even a risk of depleting the stock of certain fish. It has been mentioned previously that the plaice, for instance, appear to be being fished out of the North Sea to a dangerous extent.

What might be regarded as one of the largest experiments ever carried out was a direct result of the great war. For five years the North Sea was virtually closed to the steam trawlers; anyone who went out to fish did so at his own risk. Consequently it can be said that the great plaice grounds of the North Sea were almost completely rested. This afforded a real opportunity to see whether man's efforts as a fisherman could actually have any effect on the stock of fish present in so vast an area of water.

The statistics of the landings of plaice at the big fishing ports in the years right up to the beginning of the war were known. The landings in the years immediately following the end of the five years' rest brought about by the war were watched with the very greatest interest. Would the catches be still exactly the same as in the years before the war, or would the stock of plaice have become recuperated and so afford undeniable evidence of the effects of fishing? The findings were instructive indeed.

In the first year after the war the catches were very much greater than in the years before the war. The catches were also characterized by the presence of very great numbers of old, poorly nourished fish, the grounds being overcrowded. But in the succeeding years the numbers of plaice caught became less and less until now we are once more down to, or even below, pre-war figures. The average size of the fish too is much smaller than that of those caught

the first year after the war, showing that the fish are being removed at such a rate that they are never allowed to reach a good size. These results may be taken as direct evidence that fishing is being carried on to a dangerously heavy degree. The beneficial effects of fishing up to a certain extent, however, were shown by the fact that after the first year, when large numbers of the old plaice were removed, the growth rate temporarily improved.

The first care then of fishery research is what is known as a rational exploitation of the sea. That is, that the areas concerned shall be fished right up to their limit, without overstepping it and harming the stock for future years or upsetting too severely the balance of nature. To discover these limits the productivity of the sea must be estimated ; the life-histories of all the fishes, and animals and plants that concern them, must be worked out ; the causes of the various fluctuations that occur from year to year in the supply of different fish must be found and these fluctuations must be discriminated from those that may have been brought about by overfishing.

Although many of the methods employed in fishery research have been mentioned in the above outline of the study of two such fish as the plaice and the herring, there are still others that remain unmentioned. Space will not allow of further expansion on this subject but enough should have been said to impress the reader with the immense amount of labour that is involved in such investigations. We cannot be satisfied with one or two observations only. Day in, day out, information must be gathered from all possible sources ; statistics of fish landings, measurements of fish, samples of the bottom, collections of plankton, observations of currents, temperatures and saltness, all are needed. Furthermore we cannot be content with such information gathered over a period of only one

year. Observations must be carried through without fail from year to year, almost it seems indefinitely; for until many years are so covered no possible light can be thrown on the causes of the great natural fluctuations of the fish supply, of good or bad "survival years."

Research has also shown that it is not sufficient merely to study the conditions of the area with which one is concerned. It is necessary to know the sequence of events in other far lying regions, for all the waters of the oceans bear an intimate relation one with another in their current systems, and an alteration in the trend of a current in one locality may have far reaching effects on the conditions for life in waters many miles away. The fisheries of the North Sea are influenced to a large extent by that north-easterly drift of the Gulf Stream which, rounding the north coast of Scotland, turns southwards into the North Sea itself. That the Gulf Stream is subject to pulses seems now most probable, running one year with full force and penetrating far into the North Sea, and another year weakly. It seems that some of these pulsations may be rather tidal in nature, for it has been shown for two years at any rate that an increased flow of the Gulf Stream took place when the moon was at its nearest point to the earth and therefore exerting a greatest attraction on the earth. The periods of the moon's proximity to the earth, or nodapside, occur in eleven and a half yearly cycles. Suppose, therefore, that an increased flow of the Gulf Stream were to have a pronounced effect on the extent and distribution of the herring fisheries in the North Sea, and of this there are indications, then here is a definite means of preparing the industry for a good or bad year long in advance.

So far this chapter has outlined the type of research into fishery problems that is carried out at sea in specially equipped research vessels. There remains another side to fishery research of no less importance. The results of

the collections at sea must be worked out under favourable conditions and to this end a marine laboratory becomes a necessity. A laboratory for fishery research must be fully equipped both with staff and accommodation for study in any branch of science. There must be biologists who can deal with the collections of animals and plants made at sea ; there must be chemists to study the salinity of the water samples and gain an insight into the movements of the water masses, to study the gases and other dissolved substances in the sea water and note their interrelation with the distribution of animals and plants as shown by the biologists ; physical observations of temperature and light penetration must be worked out ; and there remain the statistical details on fish populations and catches to be dealt with, for which a special mathematical knowledge is required.

But while such laboratories will be concerned purely with research on the fisheries and the economic applications of science, others are required in which research of a more fundamental character may be carried out. In such laboratories problems, which to the lay mind appear at first sight to have no bearing on fishery research, are studied. It is quite a common occurrence in scientific research that an observation apparently of a very isolated and inconsequent nature may be developed later into an instrument with far reaching practical results. Opportunity is afforded in these laboratories for workers from universities, both of our own and other countries, to study many biological problems of a medical or other nature (see page 15).

The investigation into the best methods of preserving fish for food by freezing, and the effects of refrigeration on the actual values of the fish flesh, is a subject that has received very little attention as yet, and much study of this kind can be carried out in laboratories, results of which would be invaluable to the fishing industry.

In the laboratory also, experiments may be carried out on the rearing of fishes. At Port Erin, for instance, the laboratory possesses a special plaice hatching establishment in which many millions of plaice are reared successfully through the critical period of their lives and then liberated into the sea. Lobsters also are reared at that laboratory in the same way. In Norway it has been for many years the practice to hatch and liberate thousands of young cod in one of the fjords.

Much work is yet to be done on the artificial culture of such important food shellfish as the oyster and the mussel, and especially is it desirable in the case of the oyster to be able to rear the spat in hatcheries, so that there should always be a supply of tiny oysters to lay on the oyster beds each year and so ensure a provision for future years.

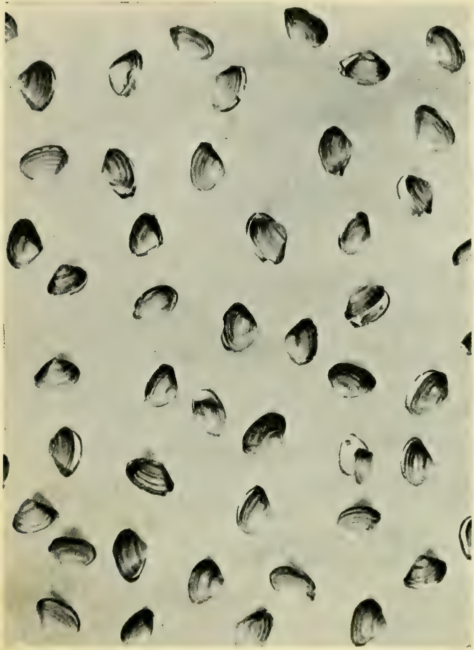
But the sea is big and the supply of food therefrom would appear to be inexhaustible and it is only natural that fishery investigations should have many critics. It is argued that the expense involved has not been worth the gain and that the sea contains resources that can never be used up by man's puny efforts ; that even if the fishermen did exhaust one ground they would be forced to move elsewhere for their supply, with the result that the fished-out grounds would have time to recover. Such suggestions appear, perhaps, to be quite sound at the moment, but what of the future ? It is probable that, as world population increases, man will turn more and more to the sea for his supplies of food. More trawlers will be built, more efficient means of capture designed. As far as we know at present the trawling areas are undoubtedly confined to the shallow plateaus and as such are limited in extent. Even now the effects of overfishing on such fish as the plaice in the North Sea are apparent, and the time must come when man's efforts will be felt, fifty, a hundred, two hundred years ahead ; who knows ? The fishermen of that

generation at any rate will be thankful that research was started so many years ago, for oceanographical research is but in its infancy. At this day it is little more than fifty years of age, and in fact it is only in the twentieth century that sufficient observations of a routine nature have been collected for comparison with future years.

It seems doubtful whether man will ever succeed in actually increasing the productivity of the sea, although even that may not be outside the bounds of possibility. At any rate it is improbable that fish-rearing carried out on its present scale will produce any appreciable effect on the fish population; for what are the few million young liberated to the many million already present in the sea? It is certainly desirable that they should be reared to more advanced stages than is at present done. Whether eventually fish hatching and rearing could be carried out on sufficiently large a scale to produce any economic results the future must decide; at least at the present day the capital expense of such an undertaking precludes its possibility.

It has been shown that the main cause of the productivity of a given area lies in the quantity of dissolved nutrient salts present in the upper water layers (page 219), and an increase in these salts would probably give rise to a greater abundance of fish life. It may be that in years to come a means for so doing will be found: there is a vast reservoir of nutrient material in the deep waters of the oceans to be drawn upon. Already the manuring of estuarine waters has been suggested as a practical means of improving shellfish cultivation.

But the aims at the present day must lie rather in estimating the limits to which the fisheries will bear depletion, and in collecting information that will enable a forecast of the state of any fishery to be made some time in advance. Beyond that it is premature to express opinion.

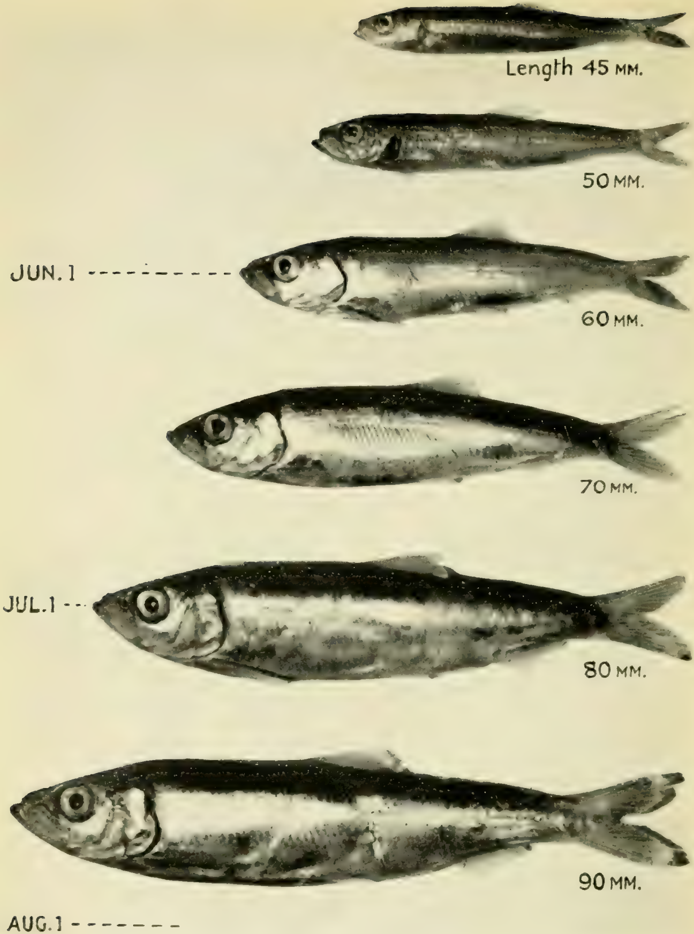


Pl. 118.

Spisula,
the chief food of adult plaice on the Dogger Bank, $\times \frac{1}{2}$. (p. 326).

Z 340.

Otolith of Plaice
Showing growth zones, $\times$ca. 20. (p. 326).



Pl. 119. *p.* 341.

Young Herring,

showing rate of growth during first year of life, actual size.
Born in December to January. (p. 329).

CHAPTER XVI

Products from the Sea

Preserved Fish

Chief among the products of the sea are the fish, and it is only just that in this chapter some mention should be made of those who become renamed after death by such names as kippers, bloaters, and Finnan haddies.

There are four methods by which fish may be preserved : by freezing, drying, salting, and smoking.

Freezing is only used to preserve the fish for short periods until they can be put on the market in a fresh condition. Steam trawlers carry ice and salt, and the fish immediately after capture are cleaned and packed away in salt and ice, where they remain until the completion of the voyage. On the return of the vessel to harbour, the fish after being sold are once more packed in fresh ice and taken direct to the shops where they are displayed for sale ready to be cooked.

The other three methods, drying, salting and smoking, are used when it is necessary to preserve the fish for longer periods so that they may be always procurable on the market when fresh fish cannot be obtained.

Drying is not practised much in northern climates, but is a very common method in warm and tropical countries where the sun's heat is sufficiently strong. The fish are generally cleaned and cut open, and laid in the sun until they are hard and dry, sometimes after a previous

application of salt. Dehydration or drying in a scientific manner has recently been introduced in Germany.

In the case of salting the cleaned fish are packed in barrels in salt; after they have settled the resulting liquor is run off, and a few more layers of fish and salt are placed on top.

Smoking is a combination of salting and drying, and upon the degree of either process the flavour of the cured fish depends. When being smoked the fish are hung up in special smoking houses. The smoke is produced by burning sawdust, which only smoulders and gives off dense volumes of smoke. Hard woods are best for the process, because soft woods contain oils and resins which vaporize and impart a taste to the fish. For this reason oak, hickory, and mahogany, among others are used.

Red herrings, bloaters and kippers, are all smoked herring, the only difference being that the degree of salting or smoking varies for each kind.

Of the three the red herring is the most strongly salted. They are thoroughly buried in salt for at least five days in large tanks and are then hung up in the smoke houses where they remain about ten days. The fish are not cut open more than is just necessary for cleaning. By remaining so long in the smoke houses they become " cured " by the antiseptic vapours arising from the burning sawdust. By this means they are fit for sending to the Mediterranean and warm countries where less thoroughly cured fish would not keep.

The bloater is much the same as a red herring except that the salting is milder, and the smoking merely for a long enough time to dry the fish and not to cure. They are only immersed in brine for a couple of hours and then smoked for a night.

A kippered herring is split down the back and then immersed for a short time, half an hour to an hour

according to size, in strong brine. It is afterwards smoked for a night.

These methods of salting and smoking fish do not apply only to herring, and large quantities of such fish as haddock and cod are similarly treated.

Another method of preserving fish is to tin them in oil. In this way sardines, which are young pilchards, are prepared for market by the French. The fish are cleaned, immersed for a short time in brine, dried and then fried for about two minutes in olive oil. They are then packed in olive oil in tins which are hermetically sealed. A similar trade is carried on in Norway only there the "sardine" is either a sprat—"Brisling"—or a young herring.

In some countries sardines or other fish may be pickled in vinegar. Fish are used in some European countries for making sausages, and are mixed with pork and flour.

Products from Fish

There are many commercial by-products to be obtained from fish, chief amongst which are certain oils, fertilizers and meals, glue, isinglass and leather.

Fish may be divided into two classes, those that contain most oil in their bodies and those that have most in their livers. Of the former the herring, the menhaden and the salmon are good examples and they furnish what is commercially known as "fish oil." This oil is used to a large extent in the manufacture of paints. To the latter group belong such fish as the cod, which yield those "liver oils" so well known for their medicinal value. Cod-liver oil, as well as that of other fish such as the shark, is used in the tanning industry for "currying" leather—making it waterproof and pliable. It is also used in the manufacture of soaps and for tempering steel.

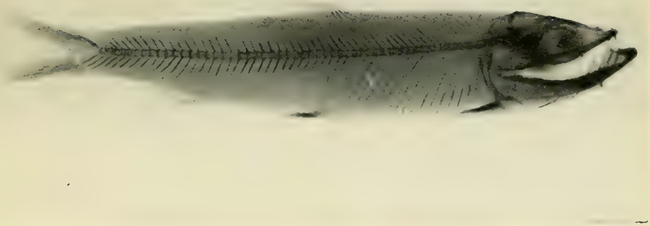
In the manufacture of fish meal all the waste parts of

the fish can be utilized. Heads, fins, bones and entrails, in fact all that remains of the fish after they have been prepared for market is taken to the meal-making factory. Until recently the great drawback to these factories has been their odour, but now an odourless process has been invented so that factories can be built in the big fishing ports in close proximity to the harbours so that no expense is incurred in transport of the offal. Into one end of the plant is placed the fish remains and from the other comes the clean dry fish meal, ready to be packed up and sold. The offal is first passed through a chamber in which it is heated and dried by means of steam pipes. After this prolonged heating the mass becomes thoroughly sterilized. The vapours and smells arising inside the chamber are carried off and dissolved in special solutions. The dried remains are then passed on to another chamber in which they are crushed and reduced to a fine powder. The meals thus obtained are of great value as food for cattle and poultry. A German firm has recently produced an extract from cods' heads which is to all appearances similar to meat extracts, and which probably is just as nourishing and can be produced at a fraction of the cost.

Fish scrap can also be dried and used as fertilizers.

Glue is obtained chiefly from such fish as the cod, haddock, and hake, and is a product of the fish's skin. The material is thoroughly washed to remove all traces of salt and then placed in steam extractors.

Isinglass is a pure gelatinous substance obtained from the swimming-bladder, or " sounds," of certain fish. Although the best material is obtained in Russia from the sturgeon, very good quality isinglass can also be manufactured from the hake. It is used chiefly for clarifying wines, although it is also used in the making of certain glass and diamond cements.



X-ray Photograph of Young Herring. (p. 331).

Pl. 120. Z 344.

Scale of Herring in its fourth winter, ×ca. 8. (p. 331).

Pl. 121. Z 345.

Pearl Oyster (*Margaritifera margaritifera*), $\times\frac{2}{3}$. (p. 346).

Ormer (*Haliotis tuberculata*), $\times\frac{2}{3}$. (p. 350).

The manufacture of leather from shark-skin is now a commercial proposition. Formerly the difficulty of removing the hard scales embedded in the skin made the production of this leather uneconomical, but several processes for doing so satisfactorily have now been discovered and patented.

Products from Whales

Among the chief products from whales are the oils which are obtained by refining down the blubber. These oils are used in the manufacture of soaps and candles. The best oil is derived from the Sperm whale, in this case the body and head of the whale are treated separately, the head oil being more valuable. The crude oil is allowed to freeze for ten to fourteen days and then it is subjected to pressure three times at different temperatures when three grades of oil are separated out. This sperm oil is very valuable for lubricating purposes. After this treatment the mass that remains is spermaceti, and this is refined by chemical treatment. The pure spermaceti is a wax with a white crystalline texture, and is used in the manufacture of cosmetics and face creams.

But by far the most valuable material obtained from the Sperm whale is ambergris. This is a concretion from the intestine of the whale, but is more often found floating in the sea or cast up on the shore. It is used in the making up of fine perfumes.

In addition to the above there are the whalebone from whalebone whales, the meat for human consumption, and the scrap remains which are used as fertilizers.

Pearls

The most valuable of the products of the sea are pearls. Though the modern recognition of pearls probably originated

with the Romans, they are mentioned in the literature of most of the early civilizations, so that to seek the beginning of the use of pearls we should probably have to go back before the birth of history to the days of primitive men who lived on shellfish and discovered in them round beads of great lustre and beauty.

Many of the bivalve molluscs form pearls but in only a very few are they of the necessary size and quality. The principal source of the finest pearls is the pearl oyster which is a very different animal from the edible oysters, all of which belong to the genus Ostrea, whereas the Ceylon pearl oyster (Plate 121) and its relatives in Australia, the Malay Archipelago, the East Coast of Africa, the Persian Gulf and elsewhere, all belong to the genus Margaritifera and are more closely allied to our common mussel. Valuable pearls are also found in fresh-water mussels in this country and throughout Europe, also in America and Asia, but they do not concern us here.

The formation of pearls has always given rise to speculation and has been the subject of much scientific investigation in the last two or three centuries. It was the belief of the ancient Hindoos that dew drops which fell within when the oyster opened its shell were later converted into pearls by the rays of the sun, while another early theory attributed their formation to the action of lightning. But it has been known for some hundreds of years now that pearls are really due to some abnormal stimulation of the tissues of the oyster, though the cause of this is still a matter for discussion. Blister pearls, which are fastened by a fine neck to the inside of the shell, and are often sawn off and used in cheap jewellery, are probably produced by sand grains which have worked their way in between the shell and the soft "mantle" which lies against it and produces it, and there is some evidence that true pearls,

formed *inside* the mantle tissue and so unconnected with the shell, may be produced in this manner. Parasites can certainly cause the formation of pearls, a view which was first advanced in 1554 and has been proved by the discovery of mummified remains of different parasites in the centre or "nucleus" of many pearls. The parasite which most frequently causes pearl formation in the Ceylon pearl oyster is the early stage of a tapeworm which becomes adult in a large ray which, as we saw in Chapter IX, habitually feeds on these oysters thereby infecting itself with the tapeworm. After becoming mature, the tapeworms lay eggs which pass into the sea where they may find a temporary home in an oyster. A temporary home if the oyster is swallowed by the ray shortly after, but a grave if the oyster should be provoked to protect itself from the irritating parasite by coating it with pearly substance. It may be that pearls are also formed round tiny granules of waste matter produced by the oysters themselves.

The process of pearl formation is perfectly straightforward. The nucleus, of whatever irritating substance that may happen to be, becomes enclosed within a tiny chamber in the tissues from the walls of which is produced the pearly substance which is composed of the same nacreous material which lines the inside of the shell and forms "mother-of-pearl." This is applied in the regular layers around the nucleus so that a round bead is gradually formed, the lustre of which is due to the concentric layers of the crystalline nacre (Plate 123 and text figure 64).

The most famous pearl fisheries in the world are those off the coast of Ceylon. The Government controls the oyster beds and only allows a fishery when a previous inspection has shown there are suitable numbers of oysters, which is by no means frequent for there have only been thirty-nine fisheries since the beginning of the last century

and only six of these since 1891. After 1907, which was the last of a remarkable series of five consecutive fisheries, there was a blank period of seventeen years. Many attempts have been made to control the supply of oysters artificially but without success for the oysters live in too deep water to be cultivated like the edible oysters in France. Indeed the words of an early writer on the subject, named James Steuart, appear only too true: "It is only when, in the infinite wisdom of the Creator of all things, the

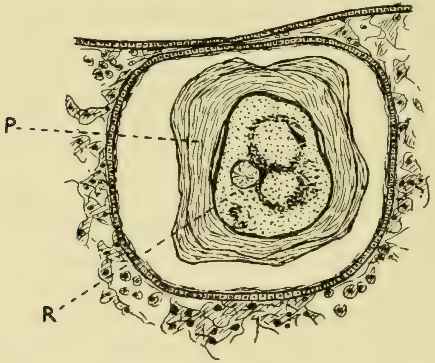
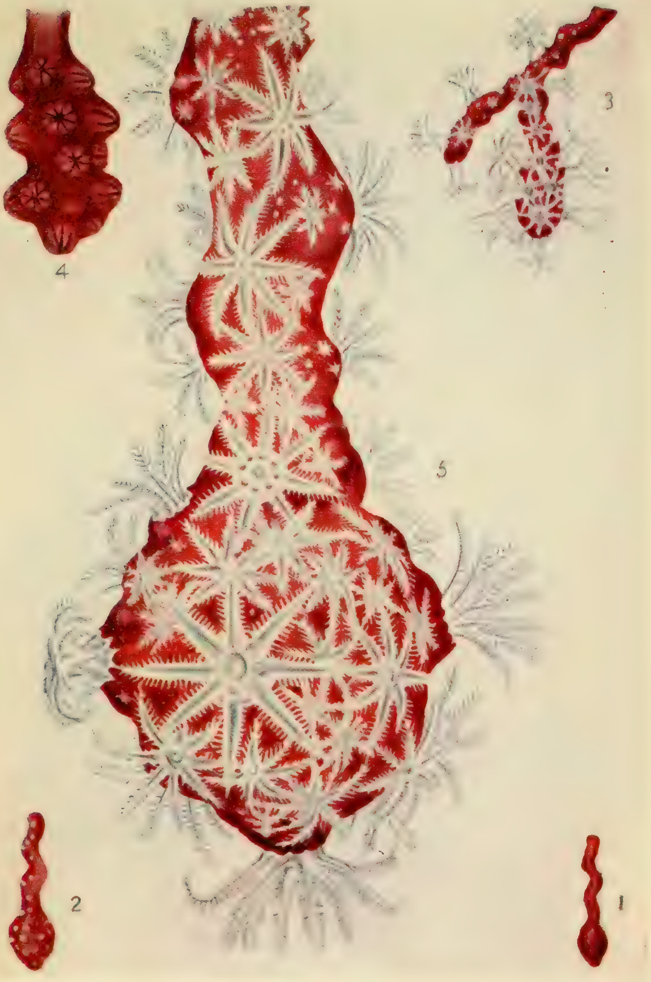


FIG. 64.—Diagram showing formation of a pearl, greatly enlarged.
R, nucleus. P, pearl forming.

oyster brood descends upon the banks suited to nourish and support it—that it comes within our limited power to watch its advancing age, and to fish up the respective deposits in succession as they approach the proper age; not letting them rest on the banks until they die off, and the pearl is lost; and carefully abstaining from disturbing those that are too young to contain it."

When a fishery is to be held, this fact is advertised in



Pl. 122. Z 348.

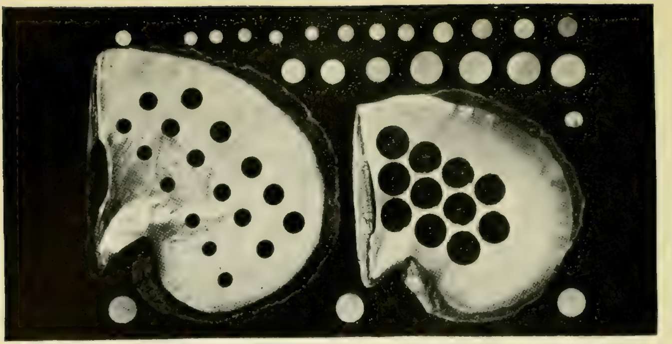
Red Coral *(Corallium nobile)*. (p. 352).

1 & 2. Pieces $2\frac{1}{2}$ months old, nat. size.

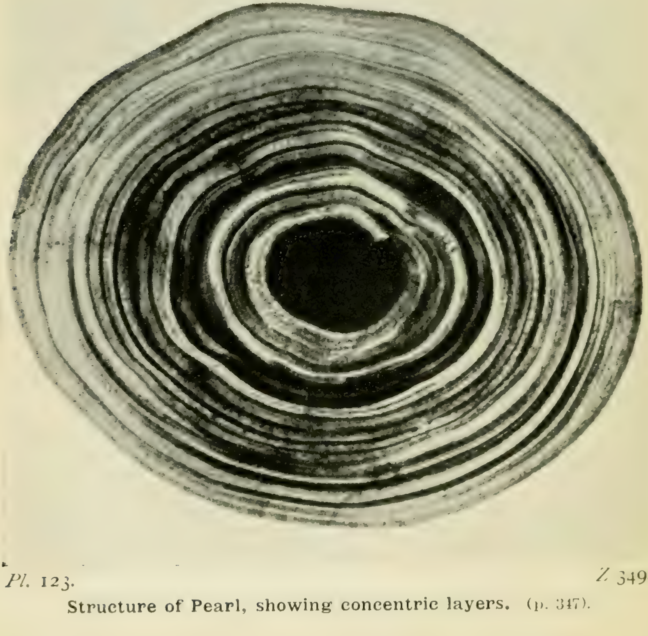
3. Portion of colony with polyps expanded, nat. size.

4. Polyps retracted, slightly enlarged.

5. Portion greatly enlarged with polyps fully expanded.



Pearl Oyster Shells cut for making buttons. (p. 350).



Pl. 123. Z 349.

Structure of Pearl, showing concentric layers. (p. 347).

many different languages throughout the newspapers of the East. On the announced date a motley collection of divers, pearl buyers, speculators, moneylenders, shopkeepers and all manner of others, collect at the temporary town of Marichchikkaddi, the headquarters of the fishery. This lasts for anything up to three months and is carefully controlled by the Government. The boats with the divers go out every morning and have to return at the sound of a gun about midday, the oysters being landed and the catch immediately divided into three equal piles, two of which are taken by the Government and later sold by auction, and the third by the divers. The separation of the pearls from the oysters is a slow and very disgusting business, the oysters being left to rot, millions of fly maggots assisting in the process. After a week the largest pearls are picked out by hand, the remaining filth with the smaller pearls washed out of the shells and, after a series of further washings, all the pearls gradually collected.

The well-known Japanese culture pearl is not artificial such as the ones discussed later in this chapter, but a true pearl produced in the usual manner. But instead of waiting until a sand grain or a parasite chances to stimulate the oyster's activities, the Japanese cultivator introduces a small body into the oyster around which the latter lays the pearl substance. The exact nature of the process is kept a close secret but takes several years.

Shells

Shells have been employed for practical purposes, for decoration and as a medium of exchange from very early times, and are still largely used in all these ways by savage tribes, and for decorative purposes by civilized peoples. The Money cowry (*Cypraea moneta*) has been extensively used in almost every part of the world for purposes of

exchange, the shells varying in value according to their size, and other shells have been similarly used in various regions.

At the present day certain shells are of considerable commercial value as the source of the mother-of-pearl used for the manufacture of such articles as buttons, studs, knife handles, brooches, fans and all manner of inlaid work. The shells principally employed are those of the large pearl oyster, Margaritifera, and the large Trochus (a tropical variety of the common top shells of our shores). There are important fisheries for the former in the Persian Gulf, the Red Sea—where the shells were artificially cultured on a large scale until the slump after the war rendered this unprofitable—the Great Barrier Reef of Australia and the Torres Straits between Queensland and New Guinea, Thursday Island being the headquarters of this fishery, and also the Pearl Islands in the Bay of Panama and various other regions in the Indian and Pacific oceans. The thick mother-of-pearl which lines the inner surface of the shell (formed as we have just seen, of the same substance as pearls) is cut out (Plate 123) by machinery and then worked up into the desired shapes.

Among the many shells used for decorative purposes we may perhaps mention one, known in the Channel Islands as the Ormer and on the Pacific coast of North America as the Abalone, the scientific name being Haliotis (Plate 121). This is really a large, very flattened limpet with a shell perforated by a curved row of openings. When cleaned and polished it is a very beautiful object and is frequently used in shops as a shade for electric lights. The flesh, incidentally, is edible and highly prized in many parts, especially in the United States where the canning of the flesh forms a considerable industry.

Artificial Pearls

Singularly enough, artificial pearls depend for their manufacture upon a marine product. About the middle of the seventeenth century, a French rosary maker called Jaquin discovered that fine flakes of a lustrous, pearl-like substance could be obtained from small fresh-water fish. He prepared a thick suspension of this and, by coating alabaster or wax beads with it, succeeded in producing extremely good imitation pearls, and, incidentally, laid the foundations of the modern artificial pearl industry.

The pearly substance, or " essence d'Orient " as it is called by the French, is really guanin, a waste product like urea, which is found in many fish, though only in a few is it suitable for manufacturing purposes. Usually it is present as a dull powder but for the preparation of pearl essence it needs to be crystalline because only in that form is it lustrous, the minute blade-like crystals reflecting light and breaking it up into the colours of the rainbow. The silvery appearance of the under side of many fish is due to the presence of crystalline guanin in the skin.

On the Continent the little fresh-water "ablette" is the main source of pearl essence, in this country the herring, and in America the sardine, herring and other fish. The crystals are extracted by washing the scales and scrubbing them with a mechanical stirrer, the sediment being finely separated in centrifuges which throw the solid matter to the sides and leave the water in the middle. Two types of " pearls " are made, one from hollow and the other from solid glass beads. The former are coated on the inside with pearl essence and gelatine, the bead being revolved rapidly until a uniform coating is obtained when the cavity is filled in with wax. The more durable solid beads which are made of opaque glass, are given six or more coats of

pearl essence usually mixed with celluloid. For the best imitation pearls the pearl essence has to be chosen very carefully because the effect produced depends on the size of the guanin crystals.

It is comparatively easy to distinguish an imitation from a real pearl. The hollow glass imitation pearls can be detected by the sharp reflection given by the glass surface and by their lightness. The solid variety are not so easy to detect, but the pearly coating can be cut off, is inflammable, and can be dissolved with amyl acetate or acetone, while the coating does not extend evenly up to the edge of the hole through which the string passes. The genuine pearl has a definite weight for its size and is somewhat iridescent ; it gives no sharp reflection from its surface and the string hole has clearly been drilled. Acetone and amyl acetate have no effect upon its surface which is, however, unlike those of the imitation varieties, attacked by acid, since the pearl is made of calcareous matter.

Precious Corals

The beautiful red coral of commerce (*Corallium nobile*) is quite unlike the " stony " corals which constitute the great mass of coral reefs, being a " false " coral more nearly allied to the Dead-men's-fingers and sea fan so common in our own waters. The red coral substance is not exposed in life but forms the central supporting framework of the colony, on the surface of which is a soft crust through which ramify the canals which connect the flower-like white feeding polyps with which the surface is dotted (Fig. 65).

Red coral is found especially in the Mediterranean, off the south of France and around the coasts of Corsica, Sardinia, and Sicily and also along the north coast of Africa from the Straits of Gibraltar to Tunis (Plate 122). It spreads into the Atlantic to some extent and is fished off the Cape

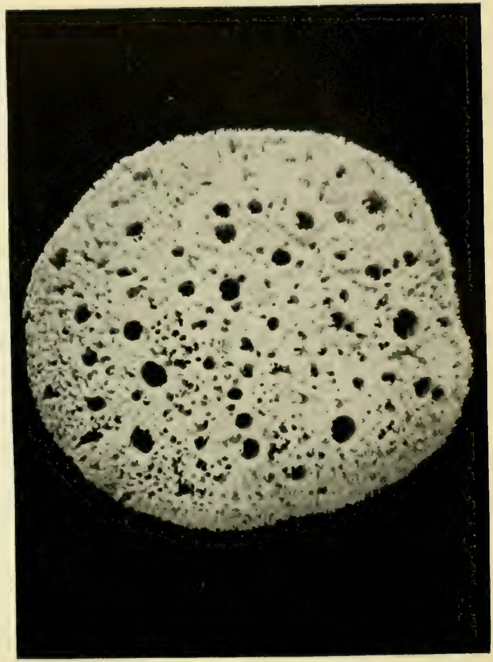
Green Turtle. (p. 355).

Pl. 124 *Z* 352.

Hawksbill Turtle. (p. 355).

Pl. 125.

Turkey-cup Sponge. (p. 357).



Honey-comb Sponge. (p. 357).

Verde Islands. A very similar red coral is found off the coast of Japan.

Coral has been prized by mankind from the very earliest times, not only as an ornament but as a charm against pests, an antidote to poisons and enchantments and as a kind of universal panacea The story is told in Greek Mythology of how after Perseus had slain the Medusa and had thrown her head on the sea shore, the sea-nymphs threw pieces of seaweed at the head and watched them turn into stone. When these stony weeds were washed back into the sea they produced seeds which developed into coral for, as the Greeks had observed, red coral is soft in water but turns to hard stone when exposed to the air.

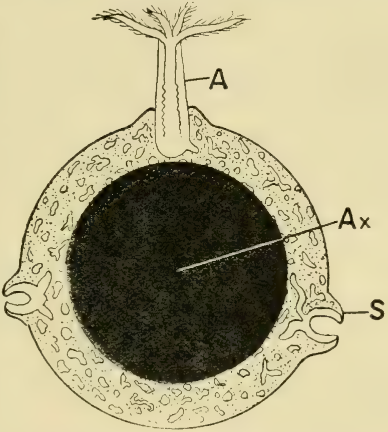


FIG. 65.—Diagram to snow the structure of a branch of red coral as seen in cross section. Ax, axis of red coral; A, feeding polyp; S, breathing polyp (x 4).

There appears to have been an extensive trade in coral with the Eastern peoples who valued it as a jewel more highly than the emeralds, rubies, and pearls they were willing to give in exchange for it, and this trade penetrated as far as India and China. The early Celtic population of Britain and Ireland also prized coral very highly, probably obtaining it from the Mediterranean by way of Gaul. An interesting evidence of this early trade, which apparently preceded the Roman Conquest, was

provided by the discovery, some years back, of a great bronze shield studded with five large pieces of coral, in the bed of the river Witham in Lincolnshire.

Right down to the end of the eighteenth century, red coral held a high place in the esteem of physicians and figured largely in their prescriptions, but the increased knowledge of chemistry and drugs finally showed that red coral was just as valuable a medicine as powdered chalk, of which it principally consists. The only relic of its original virtues which still lingers is the belief that it assists children to cut their teeth, the origin of the still prevalent custom of giving small children necklaces of coral beads.

A black coral is also mentioned in ancient and classical literature. It was also believed to have great medicinal virtues and was found in the Mediterranean and in the Red Sea and Persian Gulf. It seems to have been the black horny skeleton of Antipathes, a false coral very closely allied to our sea fan. Having no decorative value this coral is no longer used in Europe but bracelets and other articles made of it are still worn in China, Japan, the Malay Archipelago, and in the Indian Ocean, among other things as a cure for rheumatism and as a safeguard against drowning.

Turtles

Both as providers of the valuable "tortoise-shell" of commerce and of meat which is either eaten or made into the highly prized turtle-soup, the turtles are of value to mankind. Of the many kinds which inhabit warm and tropic seas, only a comparatively few are of commercial importance. Tortoise-shell (never produced by the true tortoise, a land animal) is prepared from the plates which cover the bony skeleton and form a protection for the

animal. It is obtained from the hawksbill or caret turtles (Plate 124), species of which live in warm waters throughout the Indian and Pacific Oceans and in the Atlantic from Brazil in South America to the Carolinas in North America. They are extremely ferocious beasts with powerful jaws—toothless as in all turtles but armed with horny plates—with which they seize the fish, crustaceans and large molluscs on which they feed. They are usually caught when they come ashore, especially in the breeding season when they lay their eggs in the sand. The shell, of which the best quality is found on the oldest turtles, is very thick and has to be separated from the underlying bone by heat. It can then be moulded to the desired shape by immersing it in hot water. These turtles have been caught in such numbers—2,040 kilograms of shell were exported from the Philippines alone in 1909—and usually before breeding that they are in serious danger, unless protective measures are enforced, of becoming exterminated.

The flesh of the hawksbill is of very poor quality, though, as in the majority of turtles, the eggs are much sought after as food. The green turtles (Plate 124), found in the Atlantic and Pacific and Indian Oceans, are the most valuable of the edible turtles and the source of turtle soup. They are vegetarians, browsing on the roots of the eelgrass, the bitten stalks of which rise to the surface and indicate to the fishermen the whereabouts of the turtle. They are usually caught in the " bullen," consisting of a heavy ring of metal to which is attached a deep net with a rope at the end. This is dropped over the feeding turtle which, alarmed, rises quickly, becomes entangled in the net and is hauled to the surface. The turtles are then confined in " crawls "—large pens constructed in shallow water—until needed for shipment to the market. The females are also caught on shore during the summer when they come on to

the sands to deposit their eggs. The latter also are in great demand, they are about the size of a hen's egg and are said to retain their freshness for a considerable time. Like the hawksbill, the green turtles have been decimated as a result of being perpetually pursued ; and, from being caught with ease off the Atlantic shores of North America, they now have to be sought in the remoter islands of the West Indies.

Apart from certain kinds in fresh water, the other turtles most prized as food are the salt-water terrapins which live in salt marshes along the east coast of America from Massachusetts southward as far as South America. These are captured in large numbers for the market, either taken from the marshes during the breeding season or, in the more northern regions, dug from the marshes just as they are beginning their winter sleep or hibernation. At this time they are extremely fat owing to the reserves of food they have accumulated to carry them over the winter, and so are excellent as food.

Sponges

As mentioned previously sponges are animals. There are many different kinds of sponges but only a few of any commercial importance, and these are to be found in sufficient quantities in certain localities only.

The first sponge fisheries were in the Mediterranean where from remotest antiquity the Greeks of the Ægean Islands have pursued this occupation. Until the middle of the nineteenth century the supply of sponges was derived solely from the Mediterranean waters, but in 1849 new grounds were discovered off the coasts of Florida and the Bahamas Islands. These two regions, the Mediterranean and the Bahamas waters, are still the sites of the most important sponge fisheries of the world ; and of the sponges

obtained those of the Mediterranean are of the best quality. Some of the finest sponge beds in the world lie in Egyptian territorial waters along the North African coast, stretching west from Alexandria for a distance of 300 miles to Sollum.

There are three main species of sponges fished in the Mediterranean, the Honey-comb, the Turkey-cup (Plate 125), and the Zimocca. Of these the Turkey-cup is the softest in texture. There is also another sponge known as the Elephant's-ear sponge, on account of its shape.

The Florida sponges are on the whole of a coarser texture than the Mediterranean sponges. There are several kinds known as Sheep's wool, Yellow, Velvet, Grass and Glove sponges.

Most of the sponges are fished by divers who are most skilled in the Mediterranean where the sponges on the whole grow in deeper water. The sponges may be collected either by men in diving dress—machine divers, or by naked divers. The naked divers of the Ægean are unsurpassed for their powers of endurance, and have spread from their own islands to fish the north coast of Africa, the central Mediterranean, and some even to the sponge beds in Florida. They fish, in Egyptian waters, chiefly in depths of 12 to 37 fathoms, while they have been known to go as deep as 240 and 250 feet. They generally stay down for about two minutes, though the more expert will remain under water for four minutes. The diver plunges into the water grasping in his hand a marble slab, thirty lbs. in weight, which quickly takes him to the bottom. To a ring on his arm is attached his life line. At a given signal he is hauled up by this as quickly as possible by two leather-gloved men, leaving his marble slab to be pulled up separately by another rope.

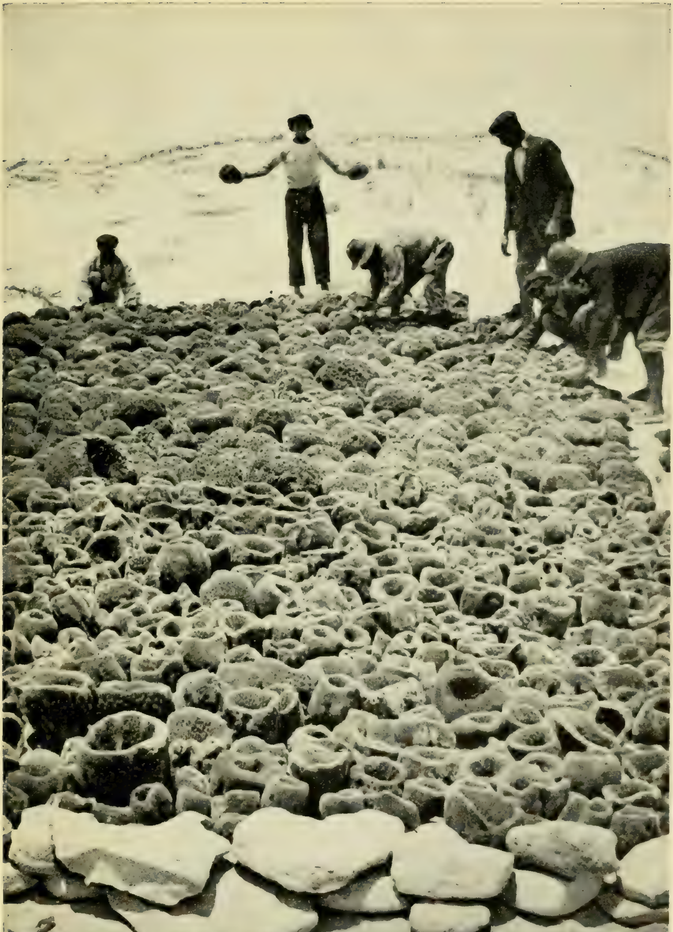
The living sponge is black and slimy in appearance owing to the living tissues which cover the skeleton. In

order to prepare it for market this living tissue must be removed, for it is only the skeleton which we use. The fresh sponges are laid on deck and stamped upon or beaten ; they are then strung together and hung over the side of the ship to macerate for a day. They are once more taken on deck and stamped upon, washed in tubs of sea water, and hung up to dry. At the end of the week they are taken ashore and spread on the sand to bake in the sun, after which they are packed up in sacks ready for sale (Plate 126).

Salt

In many parts of the world salt is obtained from the sea. A thin layer of sea water is allowed to evaporate in the sun and crystals of sea salt are deposited. In order that this may be a commercial proposition it is necessary that the summer should be long and sunny and the climate warm and free from rain. This manufacture of sea salt or "solar salt," is therefore confined to countries like Italy, Spain, and the coasts of California. The sea water is run into each of a series of shallow ponds in turn. The crystallization of the salts present is not uniform, and as the density of the water changes under evaporation the composition of the salt deposited varies. By running the water through a series of evaporating pools some of the impurities are thus removed, and certain iron salts and calcium carbonate and sulphate have been deposited before the water passes into the main pool in which most of the sodium chloride will crystallize. The finished product however still contains impurities and may be refined by recrystallization in fresh water.

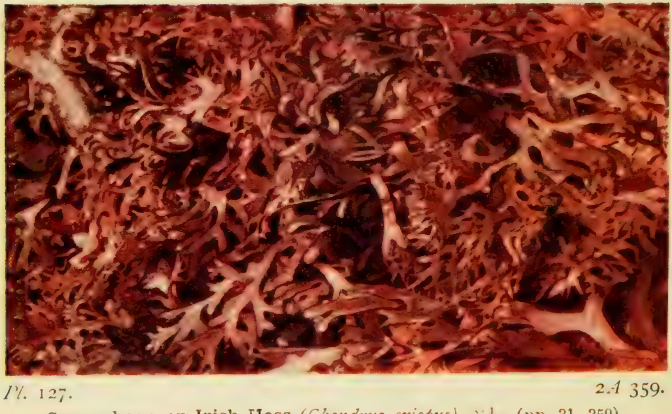
Sea salt contains a certain proportion of calcium and magnesium chlorides which are very hygroscopic and readily absorb moisture from the atmosphere. For table



Pl. 126. *2A* 358.

Sponges drying on Egyptian coast. (p. 358).

Laver *(Porphyra laciniata)*, $\times\frac{1}{3}$. (p. 359).



Pl. 127. 2 *A* 359.

Carragheen or Irish Moss *(Chondrus crispus)*, $\times\frac{1}{3}$. (pp. 31, 359).

use these impurities are removed and it is prepared in such a way that the unpleasant coagulation of salt in damp weather is avoided.

PRODUCTS FROM SEAWEEDS

There are a variety of seaweeds growing fixed to rocks around our shores and some of these are made use of by man. Around the coasts of the British Isles there are one or two species that are eaten. Of these the Carragheen or Irish Moss (*Chondrus crispus*) is eaten in Ireland, the Dulse (*Rhodymenia palmata*) in Scotland, and Laver (*Porphyra laciniata*) in England and Wales (Plate 127). These weeds are eaten in various ways, the Laver for instance being washed and then boiled for a considerable time with a slight addition of vinegar. After boiling, the laver, which has shrunken to a gelatinous mass, is made up into small cakes, coated in oatmeal, and fried. It is prepared in a very tasty manner by the Japanese, who spread it out in the sun until it is quite dry and brittle. Small pieces are then broken off and toasted over a fire and a most appetising aroma is given off.

Seaweeds are eaten in many countries but the Japanese are by far the greatest consumers, making use of many species and even culturing some.

Most of the edible seaweeds can be collected from the rocks between tide-marks, but in Japan considerable quantities of Laminarian species are torn from the bottom in deep water by fishermen with long hooks.

Another food obtained from seaweed is agar agar jelly, and this is chiefly made from red varieties. The weeds are boiled and treated until a gelatinous material is produced which can be put to various uses, such as for soups and gravies, jellies, ice-creams and sweets. It has also a certain medicinal value, and is much used by bacteriologists as

it provides a clear gelatinous medium upon which cultures of bacteria may be grown.

Seaweeds contain certain chemical bodies the extraction of which can be carried out on a commercial basis. In Scotland the wrack that is swept up on the beach by the waves is collected and burnt in kilns and iodine, bromine and potash are obtained. Great care must be taken to collect these weeds before they are rained upon as the fresh water quickly washes out the iodine. For this reason the harvesting and subsequent treatment of these weeds is a summer industry. Iodine and potash are also obtained from seaweed in other parts of the world and the industry was much encouraged in America during the great war.

A further substance, alginic acid, can also be extracted from these weeds, and the substance hardens to form a good insulating material. There are also many derivatives of the acid which can be used for making size and for other purposes.

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